Fundação para a Ciência e a Tecnologia

LABORATÓRIO DE INSTRUMENTAÇÃO E FÍSICA EXPERIMENTAL DE PARTÍCULAS

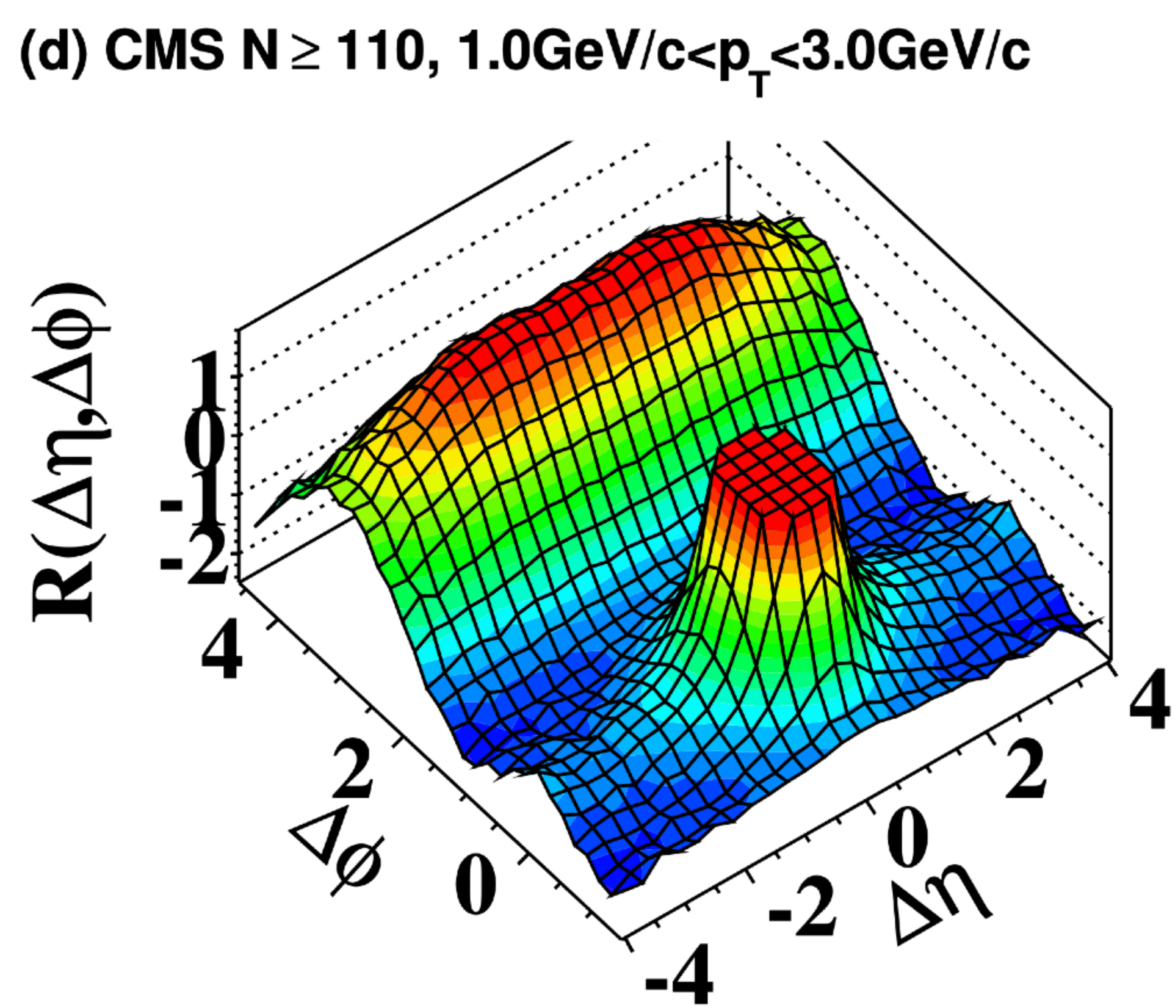
Minijet angular correlations in proton-proton collisions

Grigorios Chachamis in collaboration with
G. Calé and A. Sabio Vera

“Diffraction and gluon saturation at the LHC and the EIC”,11-06-2024, Trento, Italy

The near-side ridge effect

- The study of the Δη-Δφ correlation functions for proton-proton, proton-ion and ion-ion collisions, has drawn lots of attention in the last years. The correlation functions appear to have similar characteristics.
- Two “ridge-like structures”, the important here is the enhancement on the near side, relative azimuthal angle $\Delta\phi \approx 0$, that extends over a wide range in relative pseudorapidity ($|\Delta\eta| \approx$ up to 4).
- That long-range near-side correlation is known as the “ridge”.



CMS Collaboration, *JHEP* 09 (2010) 091

Correlation functions

- The two-particle correlation function is often defined in pseudorapidity and azimuthal space as $$C(\Delta\eta, \Delta\phi) = \frac{S(\Delta\eta, \Delta\phi)}{B(\Delta\eta, \Delta\phi)}$$
- S denotes the signal distribution which is built with particle pairs from the same event. B stands for the background distribution which involves particle pairs taken from different events; $\Delta\eta = \eta_1 - \eta_2$ and $\Delta\phi = \phi_1 - \phi_2$ are the pseudorapidity and azimuthal angle differences respectively between the particles with indices 1 and 2 which are labelling the trigger and associate particles.
- event1 = (1,2,3,4), event2 = (i,ii,iii,iv):

signal —>pairs {(1,2), (1,3), (1,4), (2,3), (2,4), (3,4)}

background —> pairs {(1,i), (1,ii), (1,iii), (1,iv), (2,i), (2,ii), (2,iii), …}

Correlation functions

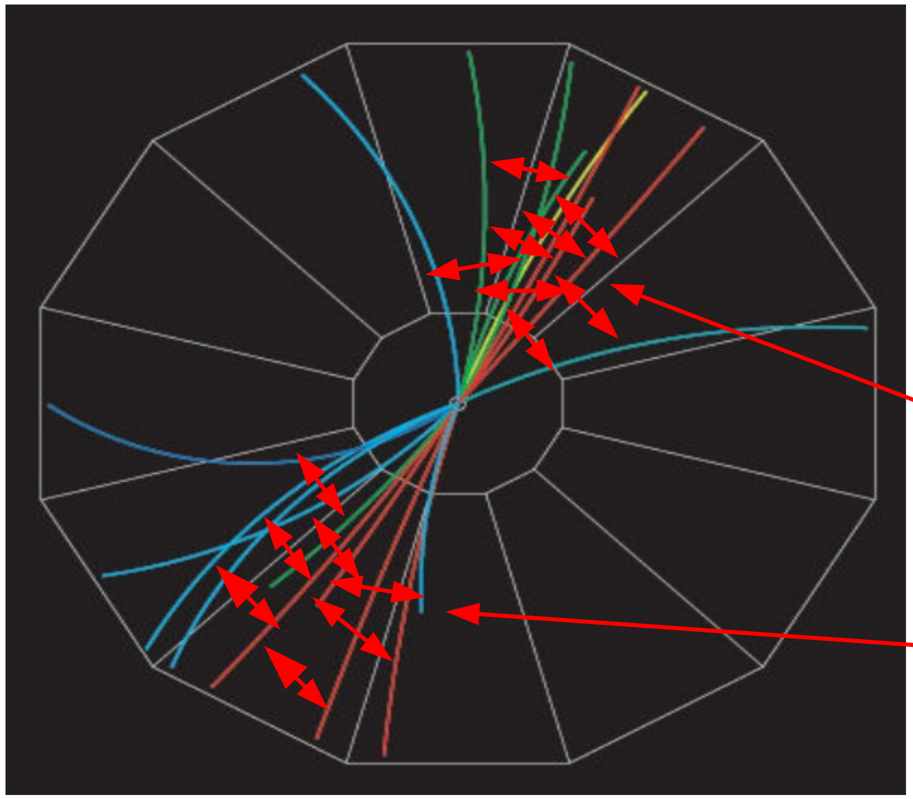
- The two-particle correlation function is often defined in pseudorapidity and azimuthal space as $C(\Delta\eta, \Delta\phi) = \frac{S(\Delta\eta, \Delta\phi)}{B(\Delta\eta, \Delta\phi)}$

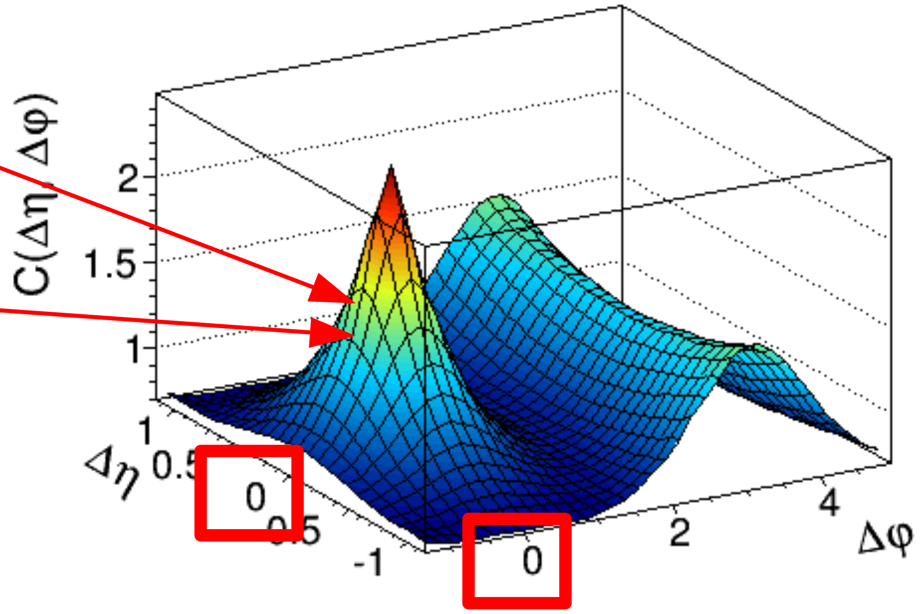
$$\tilde{\rho}(y, \vec{p}_T) = \frac{1}{\sigma_{\text{in}}} \frac{d^3\sigma}{d^3p} = \frac{1}{\sigma_{\text{in}}} \frac{d^3\sigma}{dy d^2p_T} = \frac{1}{2\sigma_{\text{in}}} \frac{d^3\sigma}{dy d\phi dp_T^2}$$

$$\tilde{\rho}_2(y_1, \vec{p}_{T1}, y_2, \vec{p}_{T2}) = \frac{1}{\sigma_{\text{in}}} \frac{d^6\sigma}{d^3p_1 d^3p_2} = \frac{1}{\sigma_{\text{in}}} \frac{d^6\sigma}{dy_1 d^2p_{T1} dy_2 d^2p_{T2}} = \frac{1}{4\sigma_{\text{in}}} \frac{d^6\sigma}{dy_1 d\phi_1 dp_{T1}^2 dy_2 d\phi_2 dp_{T2}^2}$$

$$C(1,2) = \frac{\tilde{\rho}_2(1,2)}{\tilde{\rho}(1)\tilde{\rho}(2)} \qquad C(\Delta y, \Delta\phi) = \frac{s(\Delta y, \Delta\phi)}{b(\Delta y, \Delta\phi)}$$

ΔηΔφ two-particle angular correlations

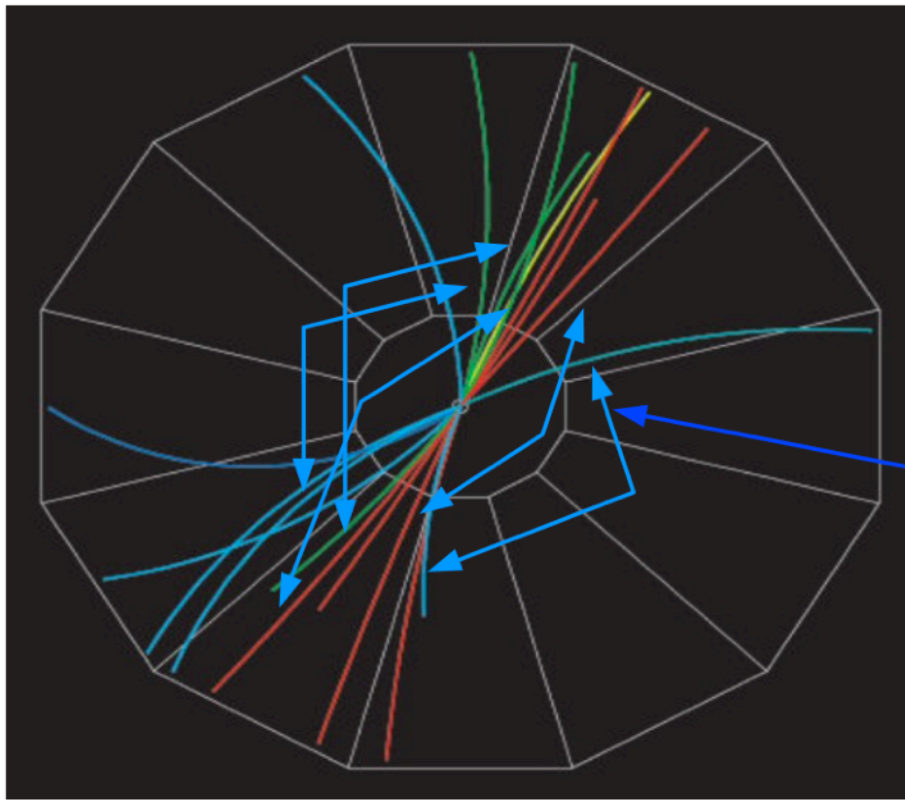


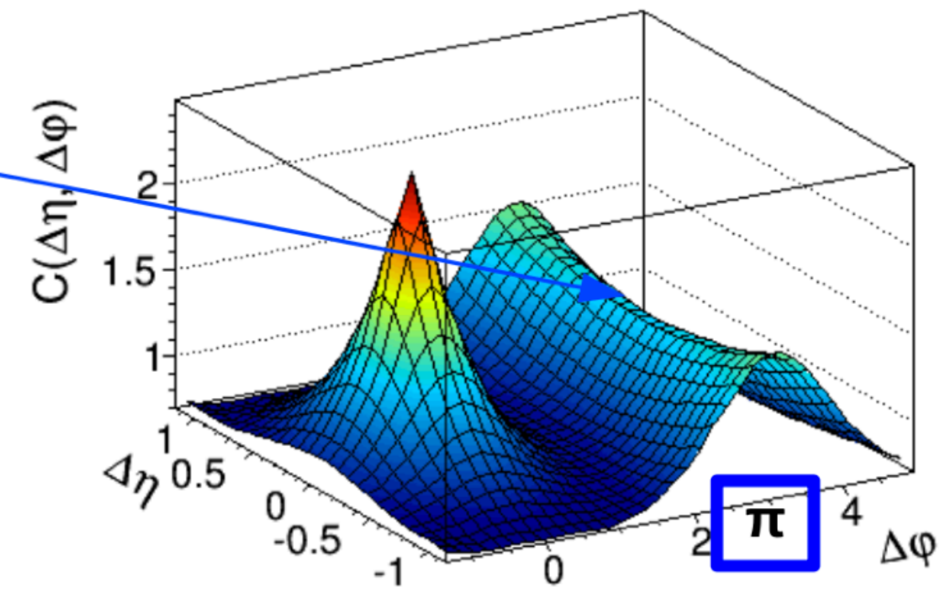


For particles from the same jet (red):

- **Δφ ~ 0**
- **Δη ~ 0**

ΔηΔφ angular correlations





For particles from from back-to-back jets (blue):

- **Δφ ~ π**
- **Δη ~ const, if avaraged over many events**

Angular correlations between the charged particles produced in pp collisions at ISR energies

K. Eggert, H. Frenzel, W. Thomé, B. Betev *, P. Darriulat, P. Dittmann, M. Holder, K.T. McDonald, T. Modis, H.G. Pugh **, K. Tittel, I. Derado, V. Eckardt, H.J. Gebauer, R. Meinke, O.R. Sander ***, P. Seyboth

1975

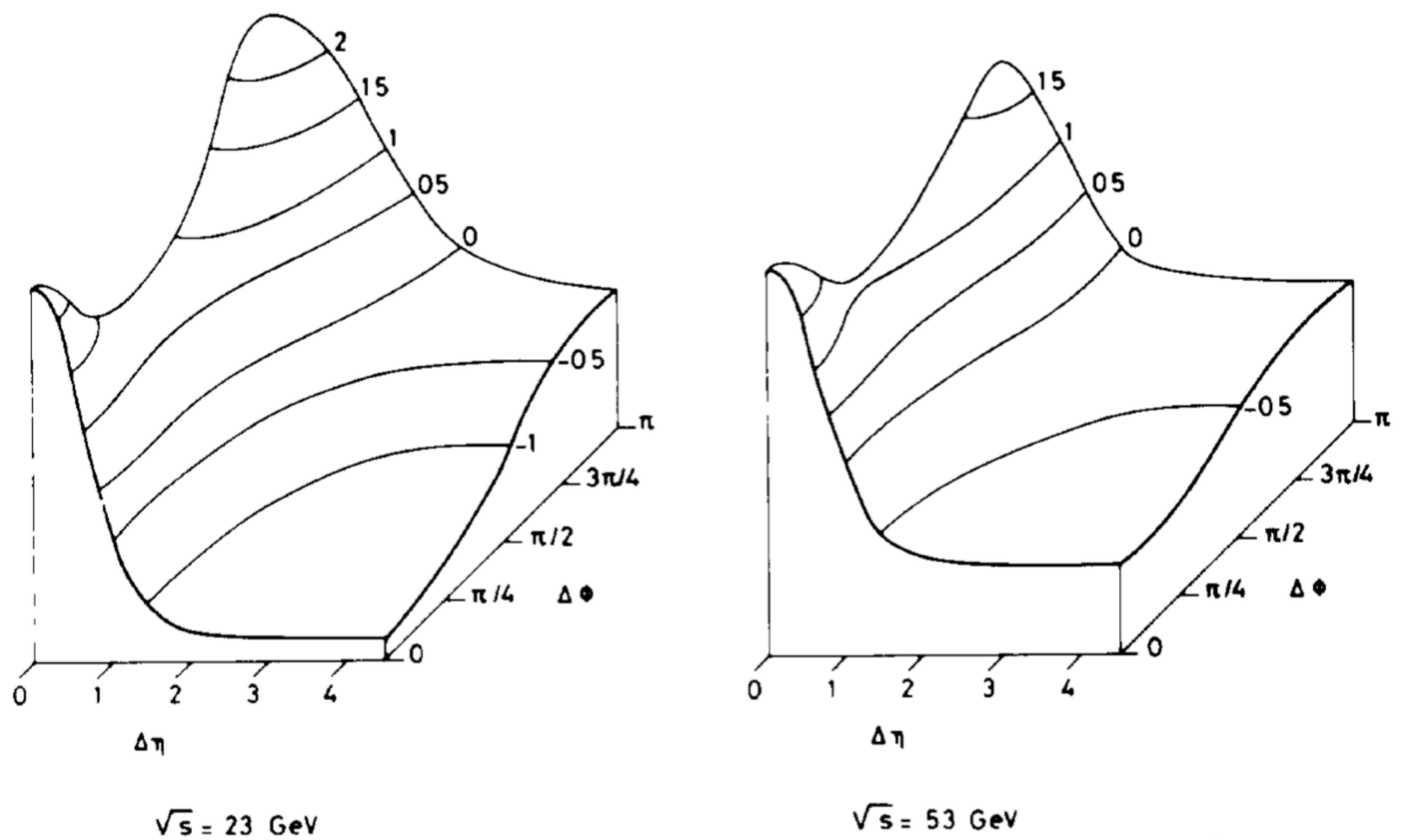


Fig 5 The measured angular correlation functions, $C^{II}(\Delta\eta, \Delta\phi)$, in units of 10^{-3} For clarity, smooth curves have been drawn through the data which have typical error bars of $\pm$ 0 4 $\times 10^{-3}$

Vol. 43 (2012) ACTA PHYSICA POLONICA B No 4

THE RIDGE EFFECT FROM p–p TO Pb–Pb (AND BACK)*

Helena Białkowska

on behalf of the CMS Collaboration

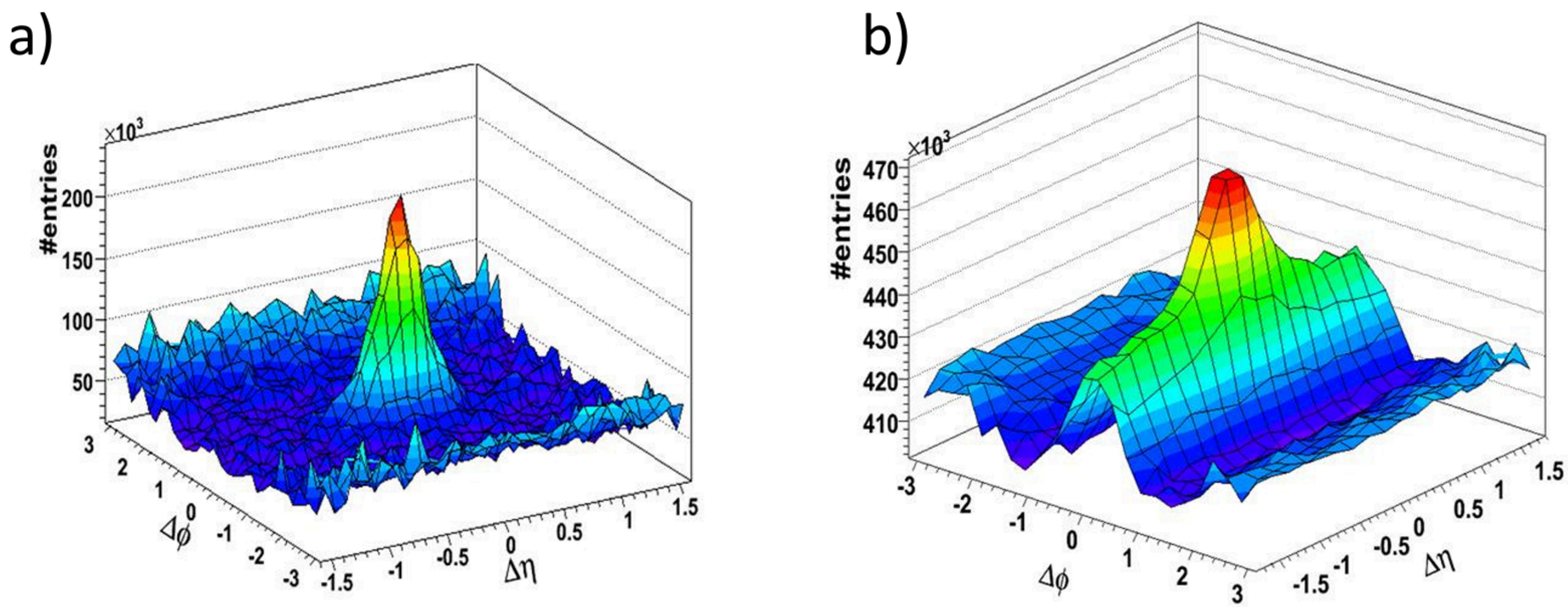


Fig. 1. Two particle correlation function for d–Au (left) and Au–Au (right) central events at $\sqrt{s_{NN}} = 200$ GeV from STAR experiment [2].

Measures of azimuthal anisotropy in high-energy collisions

Jean-Yves Ollitrault

Université Paris Saclay, CNRS, CEA, Institut de physique théorique, 91191 Gif-sur-Yvette, France

October 11, 2023

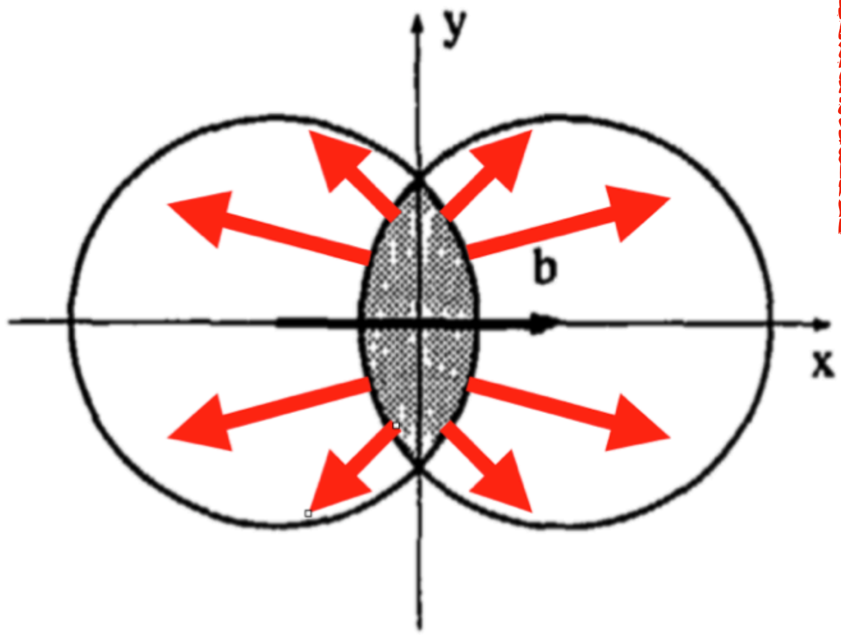


Fig. 3. Schematic view of a collision between two identical spherical nuclei at impact parameter b, in the transverse plane $z = 0$ [32]. Matter is produced in the shaded overlap area, where the participant nucleons lie. Red arrows represent pressure gradients within the produced matter. Outgoing particles typically go in the same directions as pressure gradients. This results in an elliptic anisotropy of their distribution.

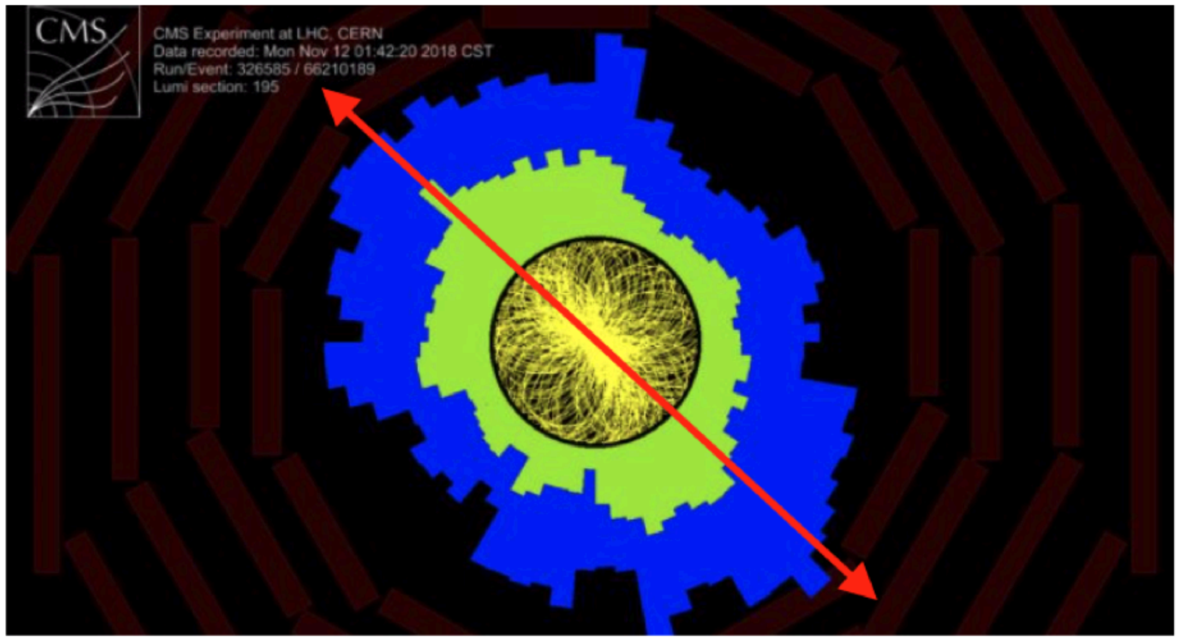
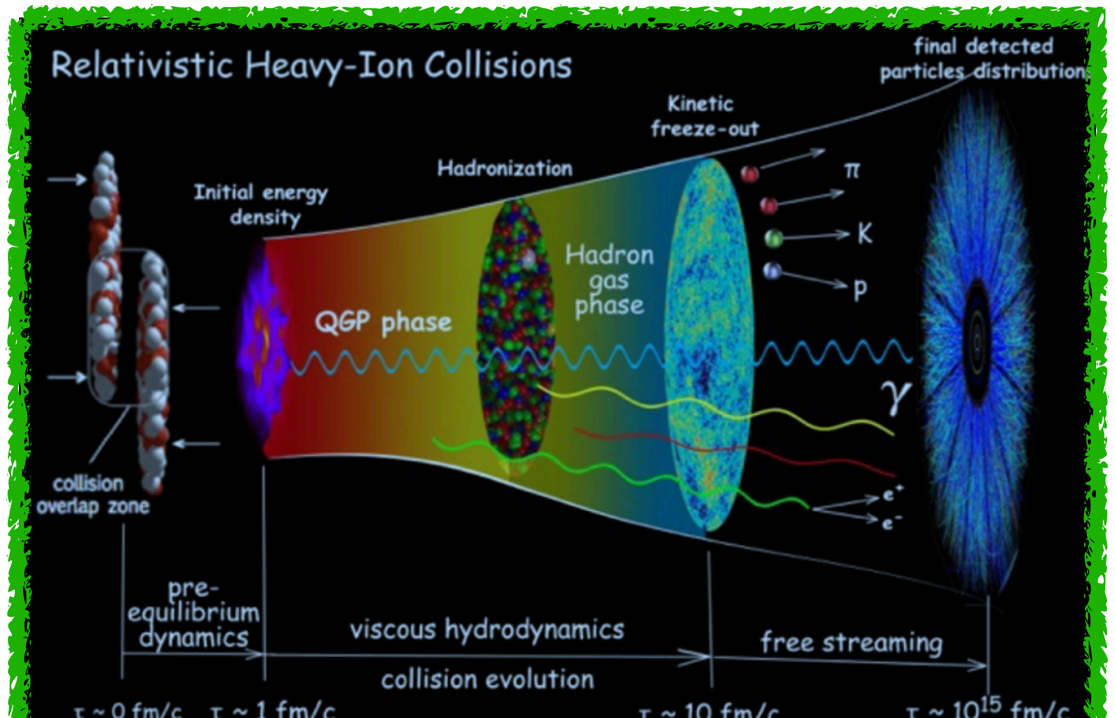


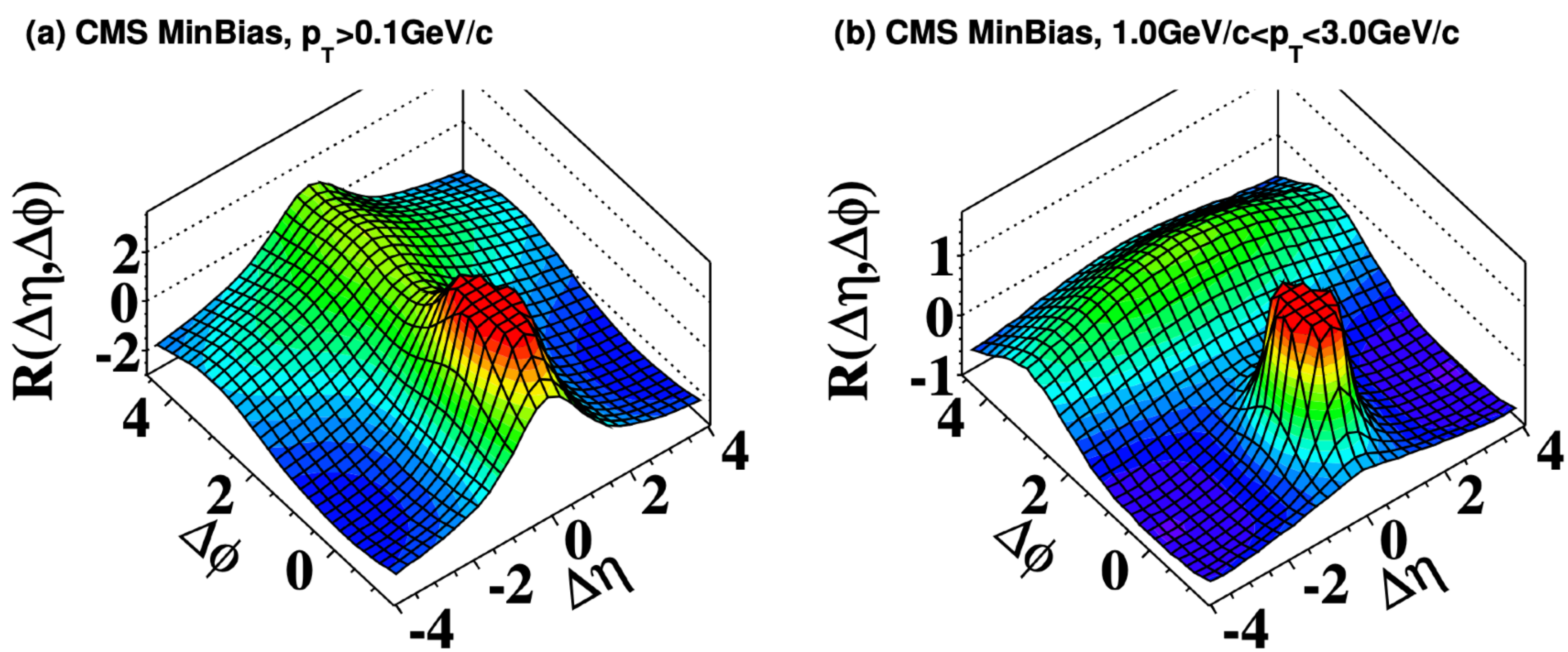
Fig. 5. Event display of a non-central Pb+Pb collision at $\sqrt{s_{NN}} = 5.02$ TeV in the transverse plane, seen by the CMS detector. The yellow lines are the charged-particle trajectories, and the green and blue shaded areas show the energy deposited in the electromagnetic and hadronic calorimeters, respectively [40]. The red arrow indicates the probable direction of impact parameter, as inferred from the elliptical shape of the event.



arXiv:1311.2574

Observation of Long-Range, Near-Side Angular Correlations in Proton-Proton Collisions at the LHC

The CMS Collaboration*



taken from https://arxiv.org/pdf/1009.4122.pdf

Observation of Long-Range, Near-Side Angular Correlations in Proton-Proton Collisions at the LHC

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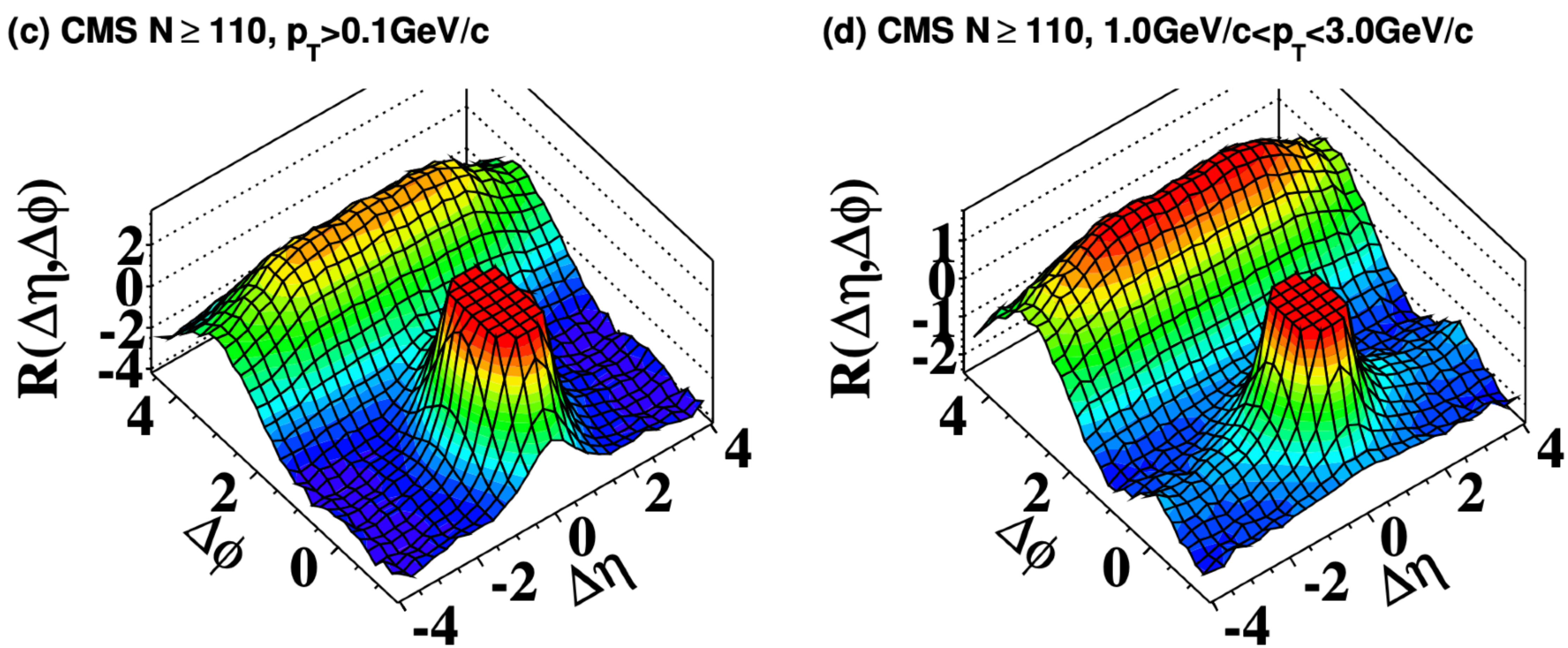
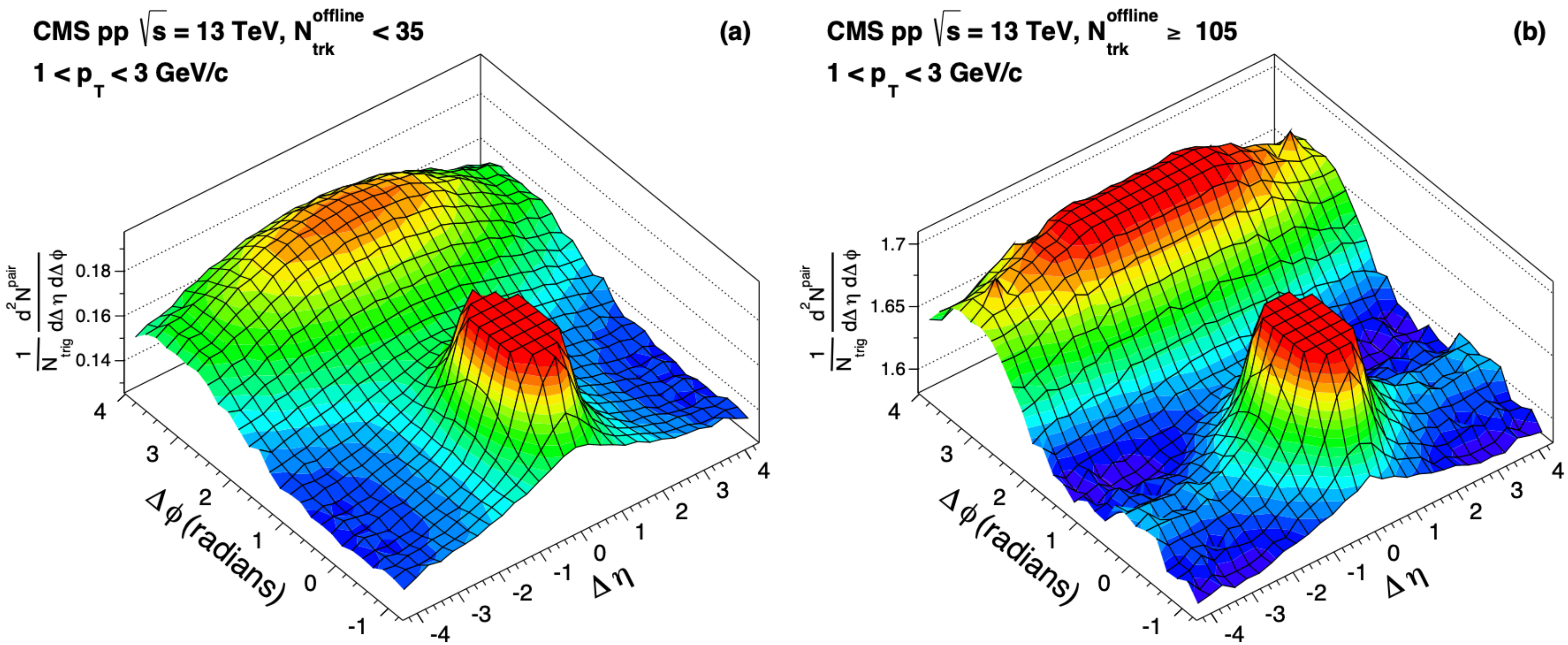


taken from https://arxiv.org/pdf/1009.4122.pdf

Measurement of long-range near-side two-particle angular correlations in pp collisions at $\sqrt{s} = 13\,\text{TeV}$

The CMS Collaboration*

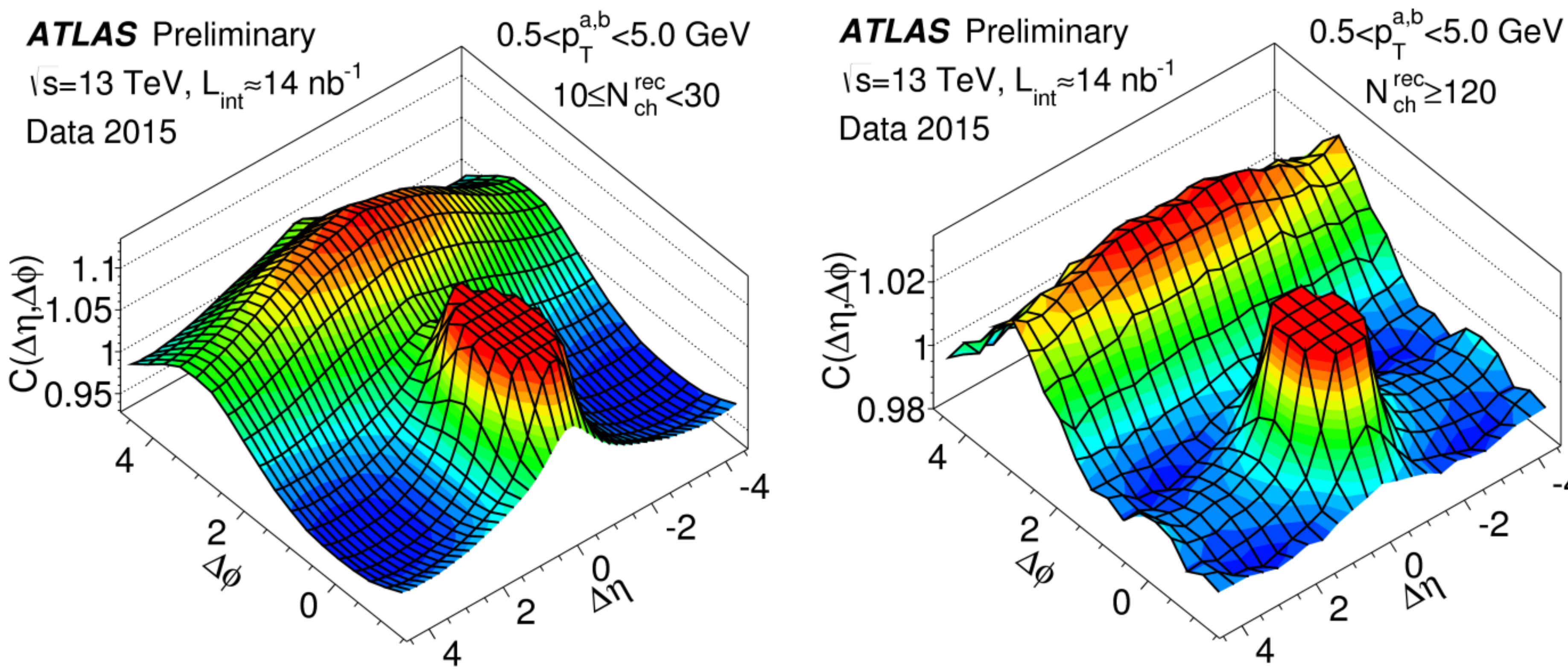


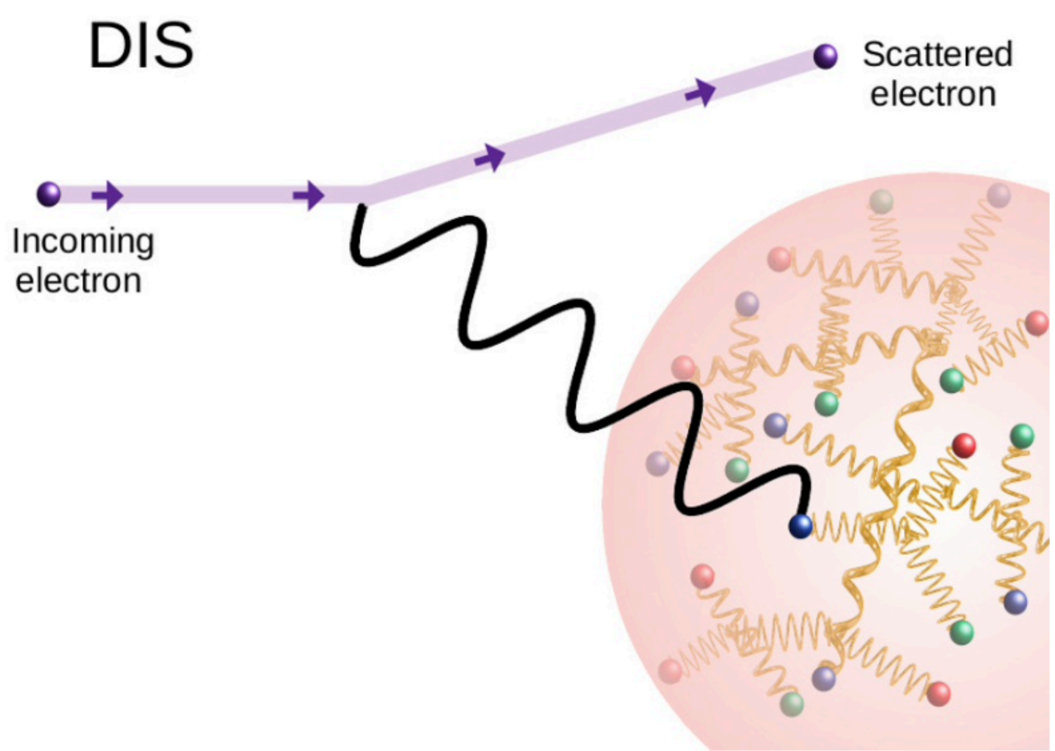
taken from https://arxiv.org/pdf/1510.03068.pdf

ATLAS measurements of the ridge in proton-proton collisions at 13 TeV

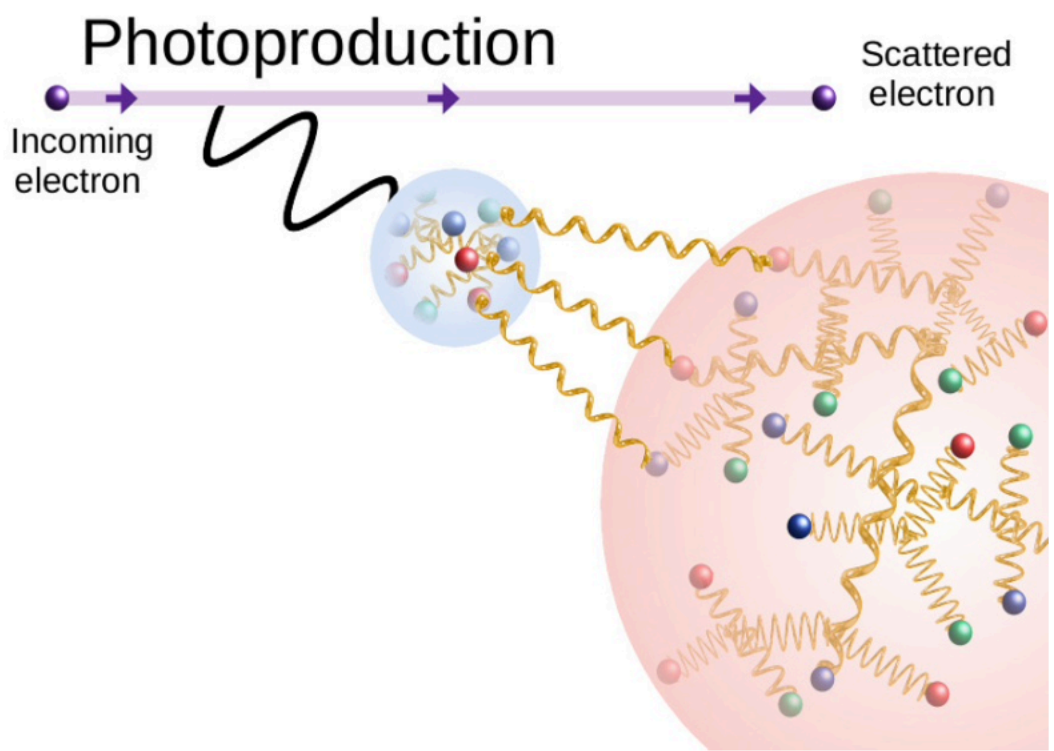
ATLAS has completed a preliminary measurement of two-particle correlations in 13 TeV proton-proton collisions at the LHC using data collected during a low-luminosity run in June 2015

24 July 2015 | By ATLAS Collaboration





(a) Neutral current deep inelastic scattering.



(b) Resolved photoproduction.

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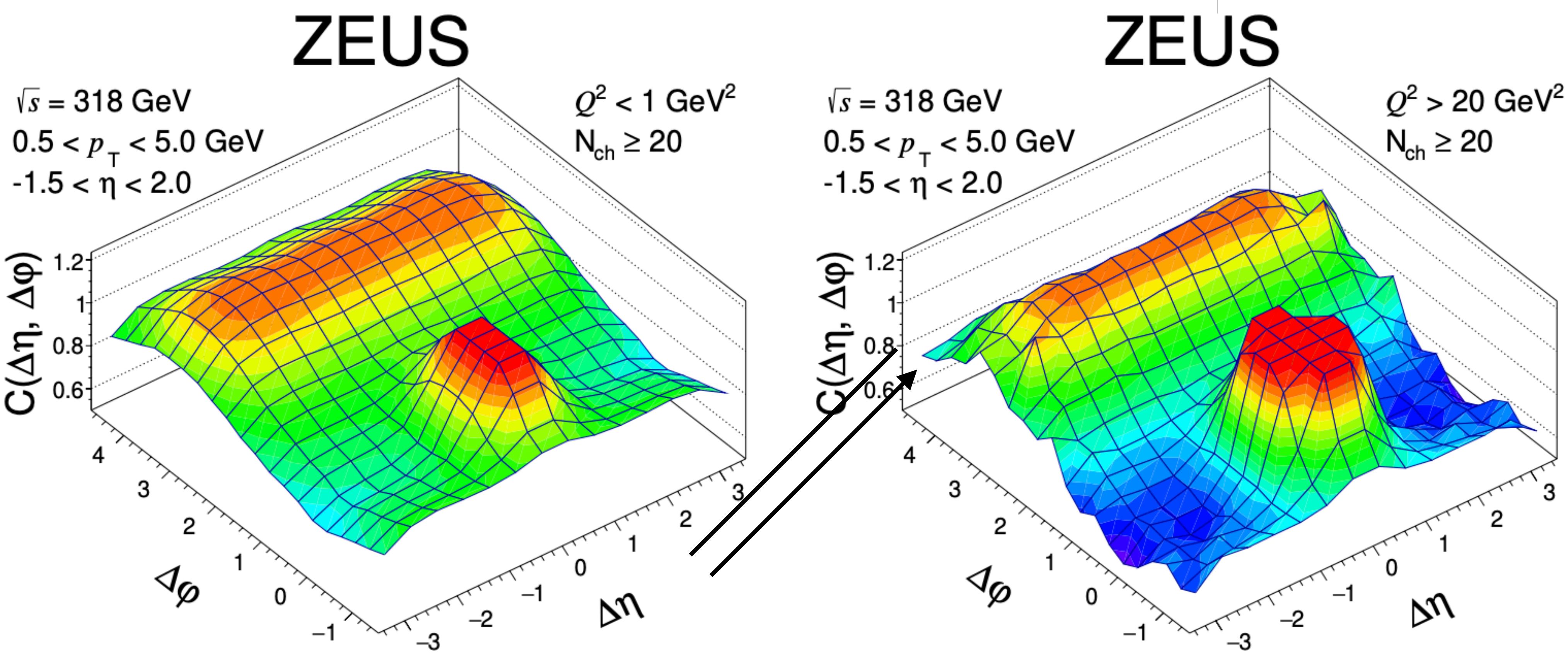
Azimuthal correlations in photoproduction and deep inelastic ep scattering at HERA



(a) Photoproduction.

(b) NC DIS with $Q^2 > 20\,\text{GeV}^2$.

Figure 3. Two-particle correlation $C(\Delta\eta, \Delta\varphi)$ in (a) photoproduction and (b) NC DIS with $Q^2 > 20\,\text{GeV}^2$. The peak near the origin has been truncated for better visibility of the finer structures of the correlation. The plot has been symmetrised along $\Delta\eta$. No statistical or systematic uncertainties are shown.

is no indication of a double ridge, which was observed in high-multiplicity $p + p$ and p+Pb

Measurements of Two-Particle Correlations in e^+e^- Collisions at 91 GeV with ALEPH Archived Data

Anthony Badea,[1] Austin Baty,[1] Paoti Chang,[2] Gian Michele Innocenti,[1] Marcello Maggi,[3] Christopher McGinn,[1] Michael Peters,[1] Tzu-An Sheng,[2] Jesse Thaler,[1] and Yen-Jie Lee[1,*]

[1] *Massachusetts Institute of Technology, Cambridge, Massachusetts, USA*
[2] *National Taiwan University, Taipei, Taiwan*
[3] *INFN Sezione di Bari, Bari, Italy*

(Dated: November 27, 2019)

"In contrast to the results from high multiplicity pp, pA and AA collisions, where long-range correlations with large pseudorapidity gap are observed, no significant enhancement of long-range correlations is observed in e+e– collisions. The data are compared to generators that do not include additional final-state interactions of the outgoing partons. The results are better described by the pythia and sherpa generators than herwig."

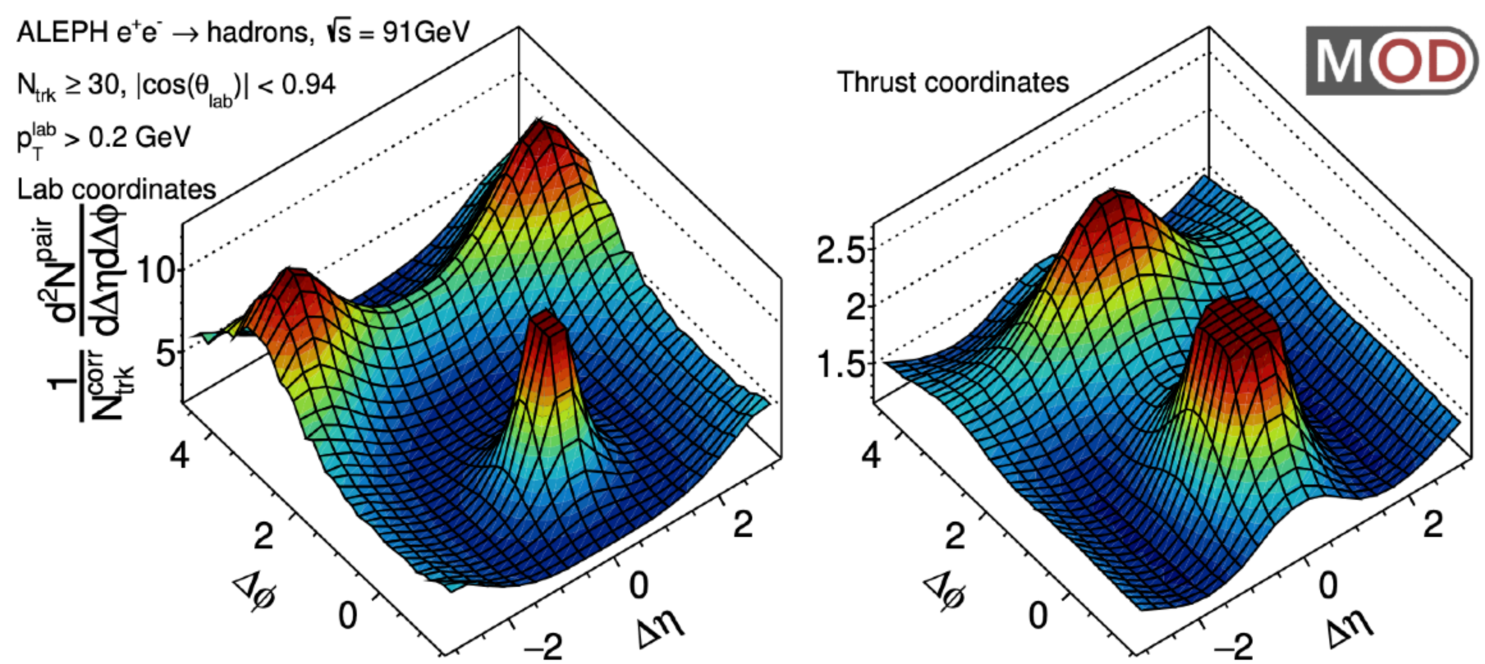
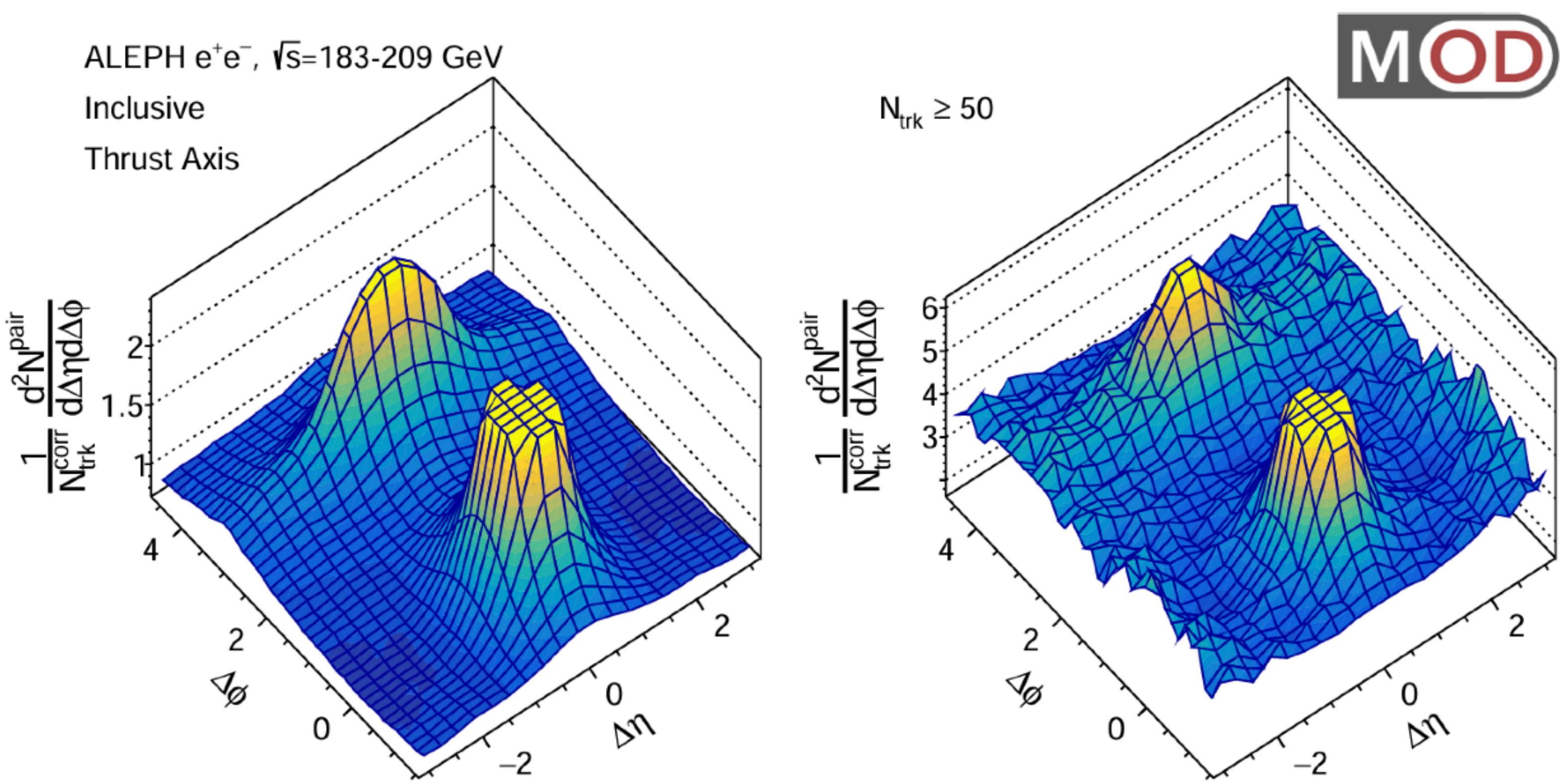


FIG. 1: Two-particle correlation functions for events with the number of charged particle tracks in the event $N_{\rm trk} \geq 30$ in the lab coordinates (left) and thrust coordinates (right) analyses. The sharp near-side peaks arise from jet correlations and have been truncated to better illustrate the structure outside that region.

Long-range near-side correlation in e^+e^- Collisions at 183-209 GeV with ALEPH Archived Data

Yu-Chen Chen,[1] Yi Chen,[1] Anthony Badea,[2] Austin Baty,[3] Gian Michele Innocenti,[4] Marcello Maggi,[5] Christopher McGinn,[1] Michael Peters,[1] Tzu-An Sheng,[1] Jesse Thaler,[1] and Yen-Jie Lee[1,*]



"…A long-range near-side excess in the correlation function has been identified in the analysis when calculating particle kinematic variables with respect to the thrust axis."

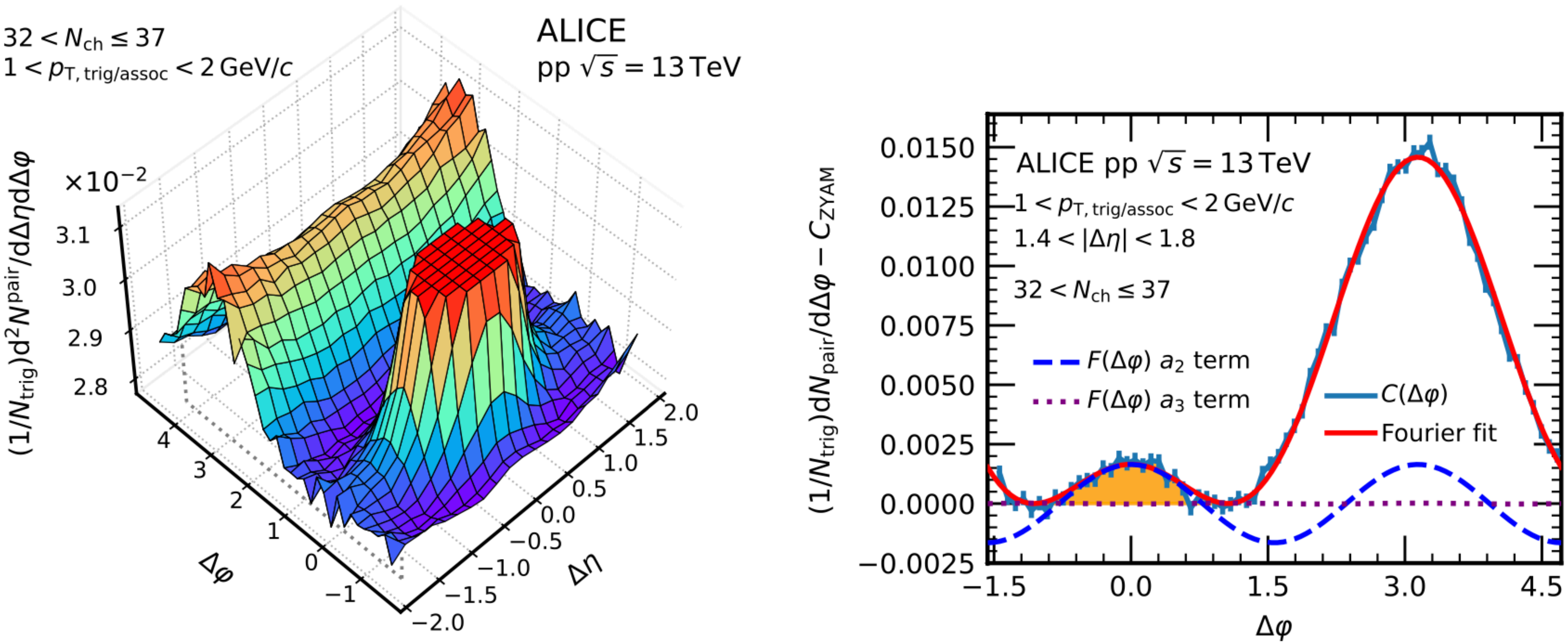
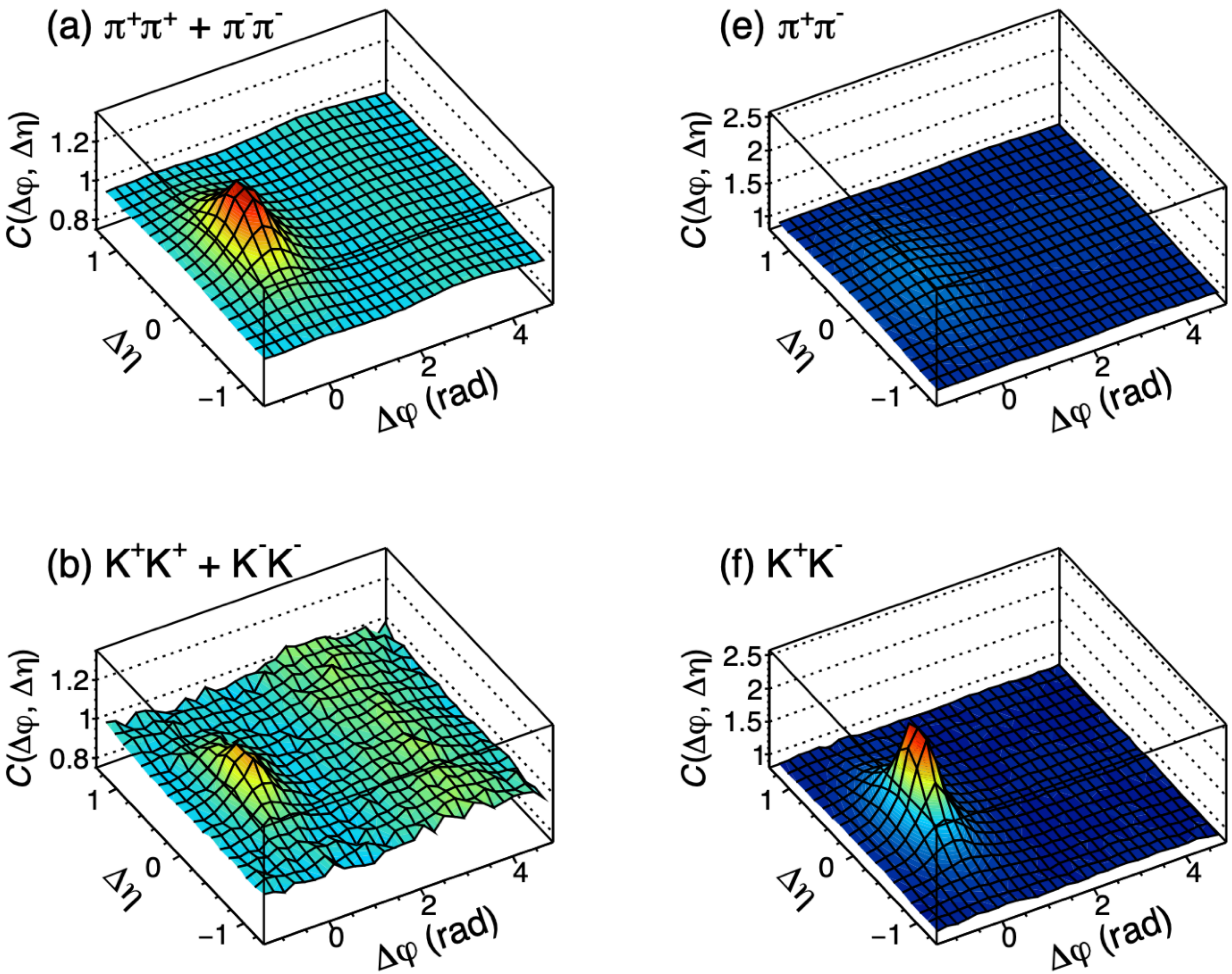


Figure 1: Two-particle per-trigger yield measured for charged track pairs with $1 < p_{T,trig} < 2\,\mathrm{GeV}/c$ and $1 < p_{T,assoc} < 2\,\mathrm{GeV}/c$ within the multiplicity range $32 < N_{ch} \leq 37$. The jet fragmentation peak has been truncated to ensure a better visibility of the long-range structure. The right panel shows the zero-suppressed projection to $\Delta\varphi$ overlaid with $F(\Delta\varphi)$ (red line) and the area in which the ridge yield is extracted (shaded area). The blue and purple lines represent the second and third harmonic terms of $F(\Delta\varphi)$.

CERN-EP-2016-322
23 December 2016

Insight into particle production mechanisms via angular correlations of identified particles in pp collisions at $\sqrt{s} = 7$ TeV

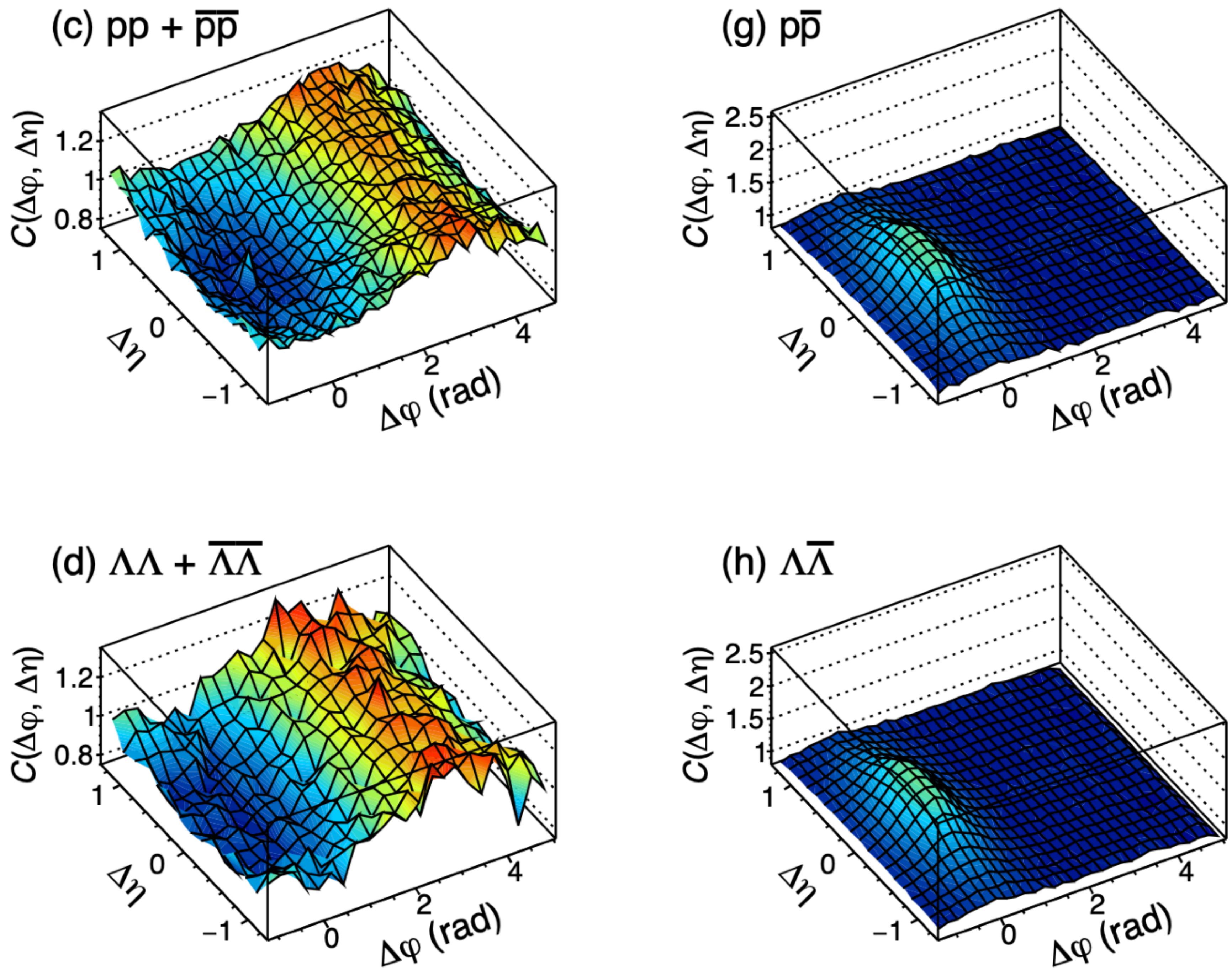
ALICE Collaboration*



CERN-EP-2016-322
23 December 2016

Insight into particle production mechanisms via angular correlations of identified particles in pp collisions at $\sqrt{s} = 7$ TeV

ALICE Collaboration*

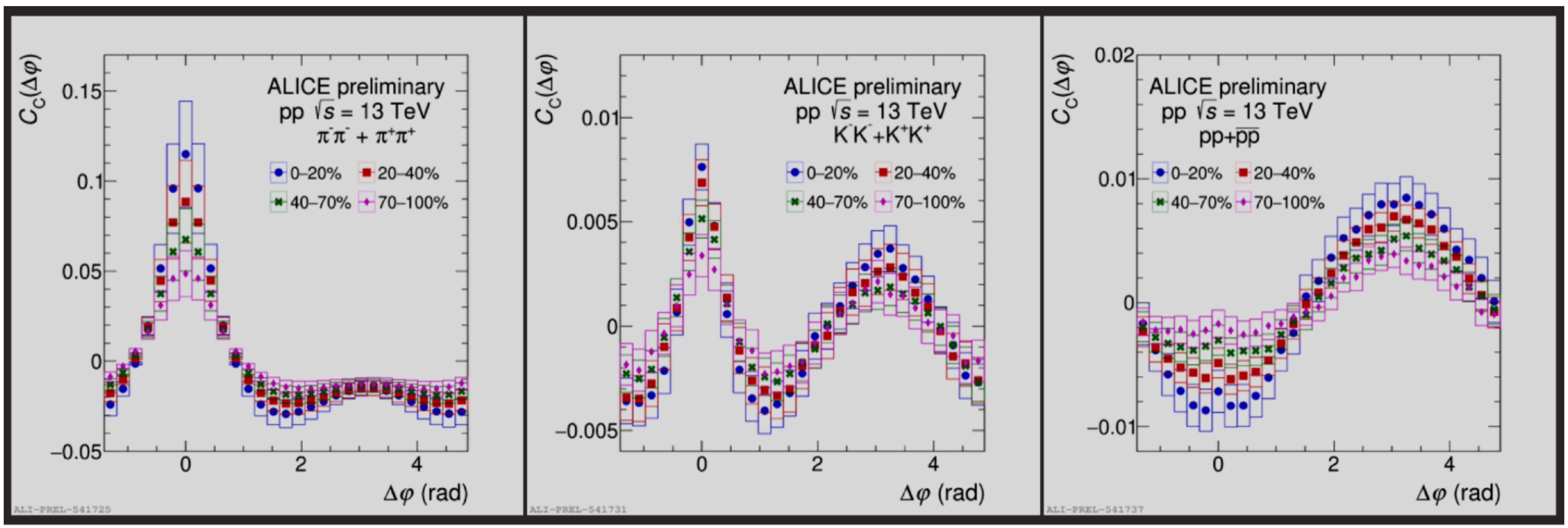


arXiv:2311.09833v2 [nucl-ex] 13 Feb 2024

1

Two-particle angular correlations of identified particles in pp collisions at $\sqrt{s}$ = 13 TeV with ALICE

Daniela Ruggiano (for the ALICE Collaboration)



“In particular, the baryon–baryon (antibaryon–antibaryon) pairs show a considerable depletion called anticorrelation”

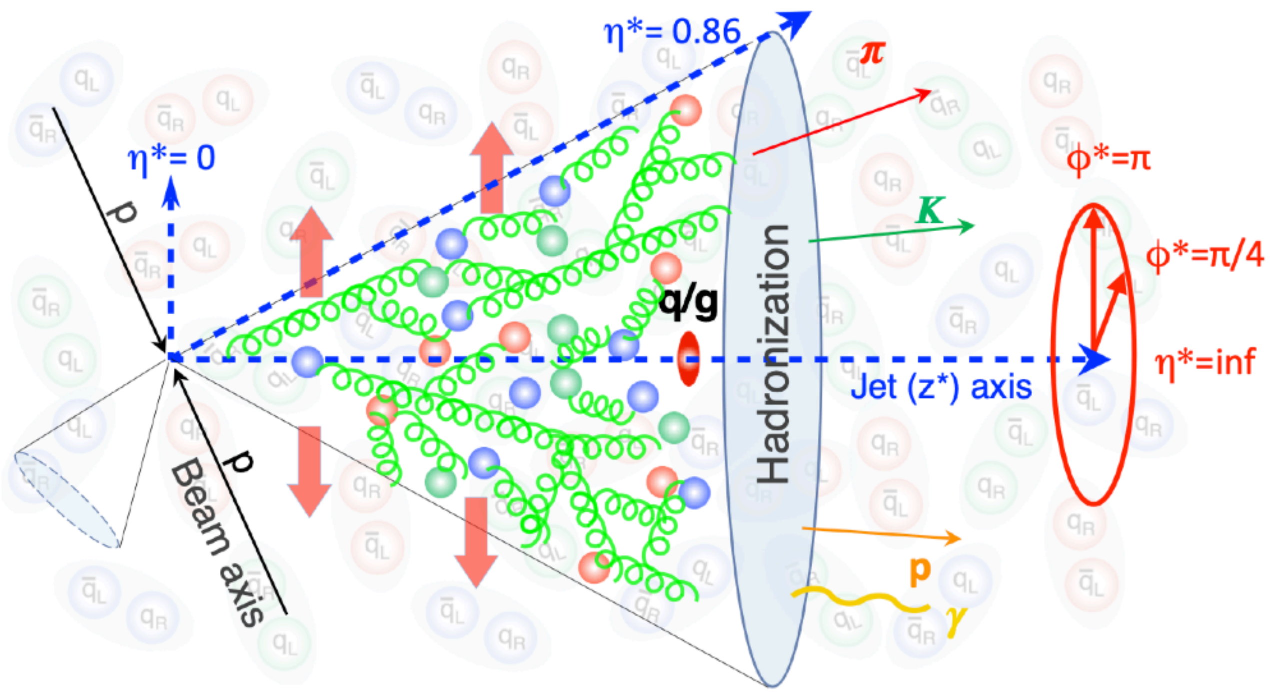
CMS-HIN-21-013 ; CERN-EP-2023-281

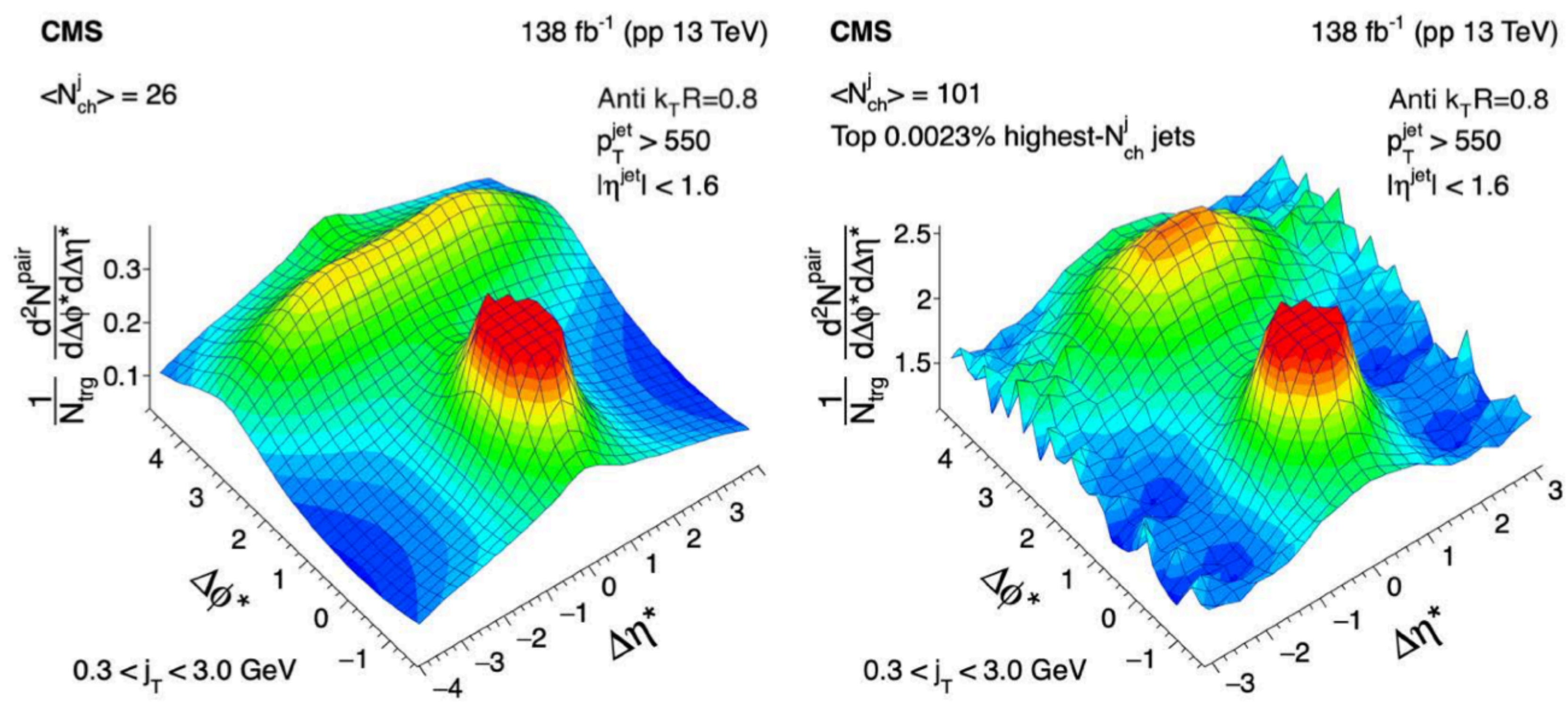
Observation of enhanced long-range elliptic anisotropies inside high-multiplicity jets in pp collisions at $\sqrt{s} = 13$ TeV

CMS Collaboration

28 December 2023

Submitted to Phys. Rev. Lett.





The near-side ridge effect

- There are two mainstream mechanisms (and many others) that give an explanation of the ridge effect in small systems (proton-proton and proton-ion collisions)

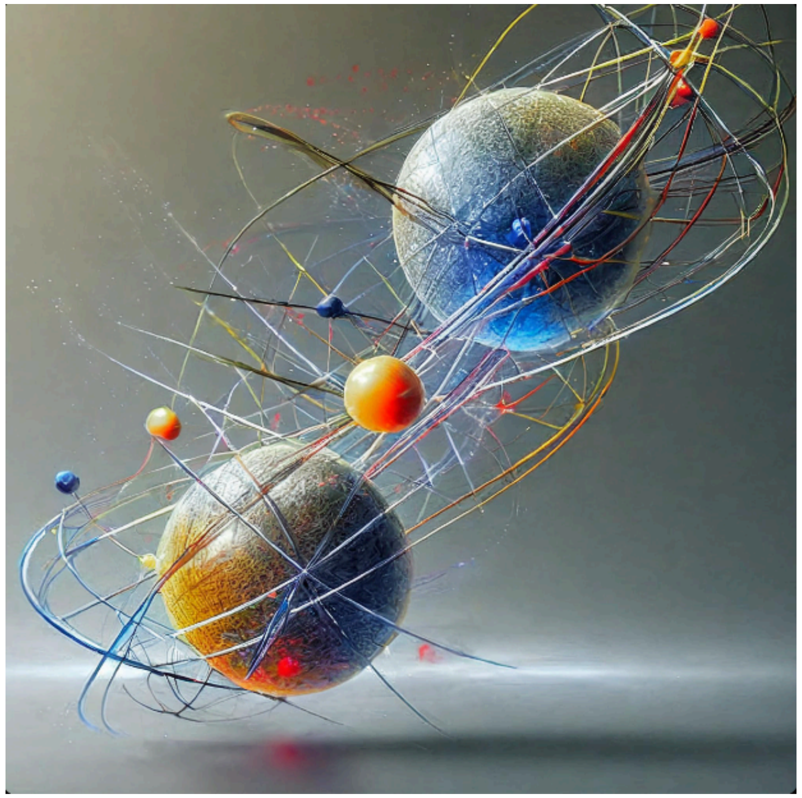
- The ”domain structure of the target” and the ”glasma graph approach” —**initial state mechanism**— within the Color Glass Condensate effective field theory (CGC).

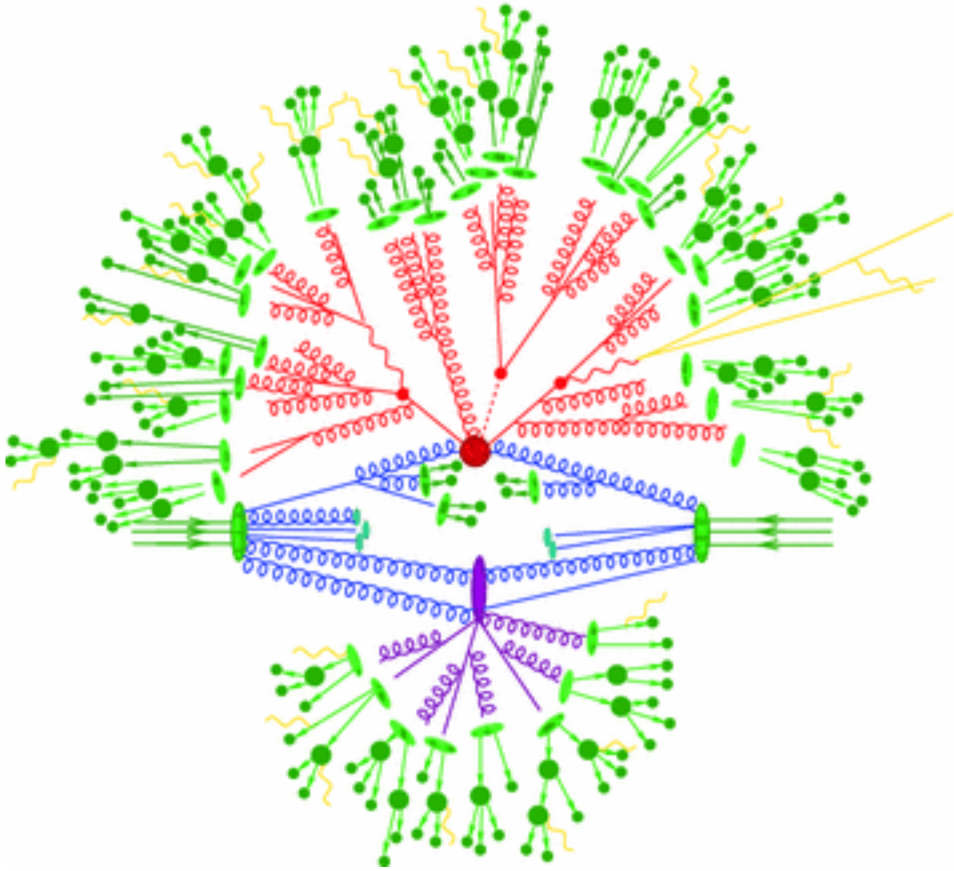
- The viscous relativistic hydrodynamics —**final state mechanism**— strong final state evolution described by hydrodynamics. Collectivity that implies a strongly coupled quark gluon plasma (QGP) that flows.

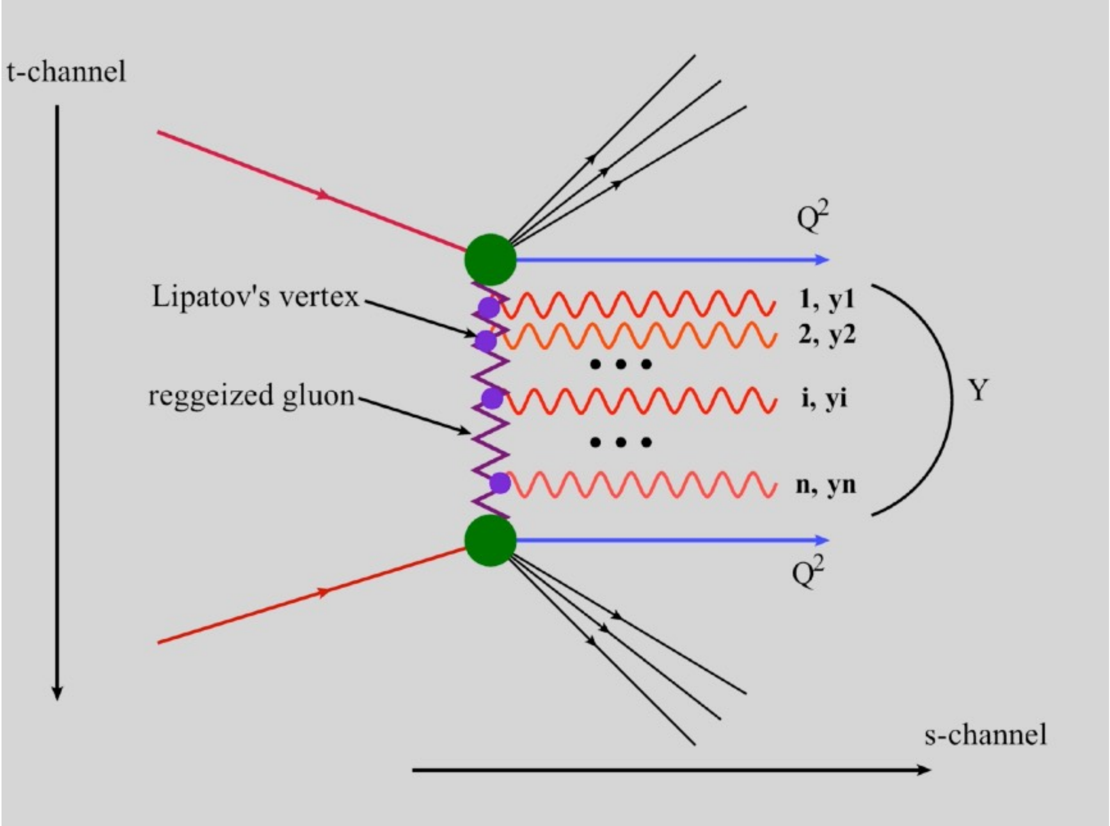
The near-side ridge effect

- The study of two-particle correlations is a powerful tool in exploring the underlying mechanisms of particle production.
- How do ridge-like structures emerge in perturbative Quantum Chromodynamics (QCD) in multiparticle production?
- Up to which degree can the ridge effect in proton-proton collisions be explained by the first principles of QCD and how does it generalize to heavy ion collisions?

one step between: from particles to minijets (partons)





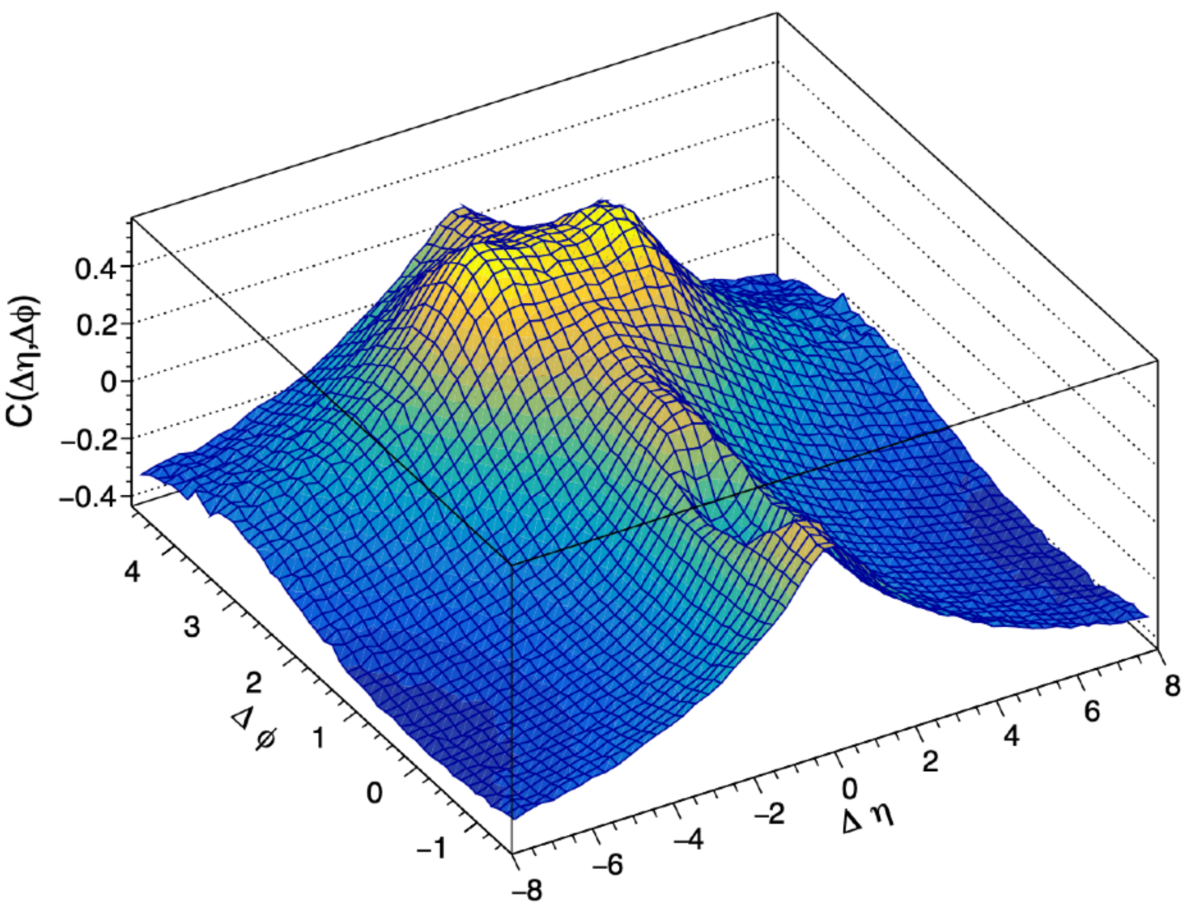

t-channel
Q2
Lipatov's vertex
1, y1
2, y2
reggeized gluon
i, yi
Y
n, yn
Q2
s-channel

First principles pQCD?

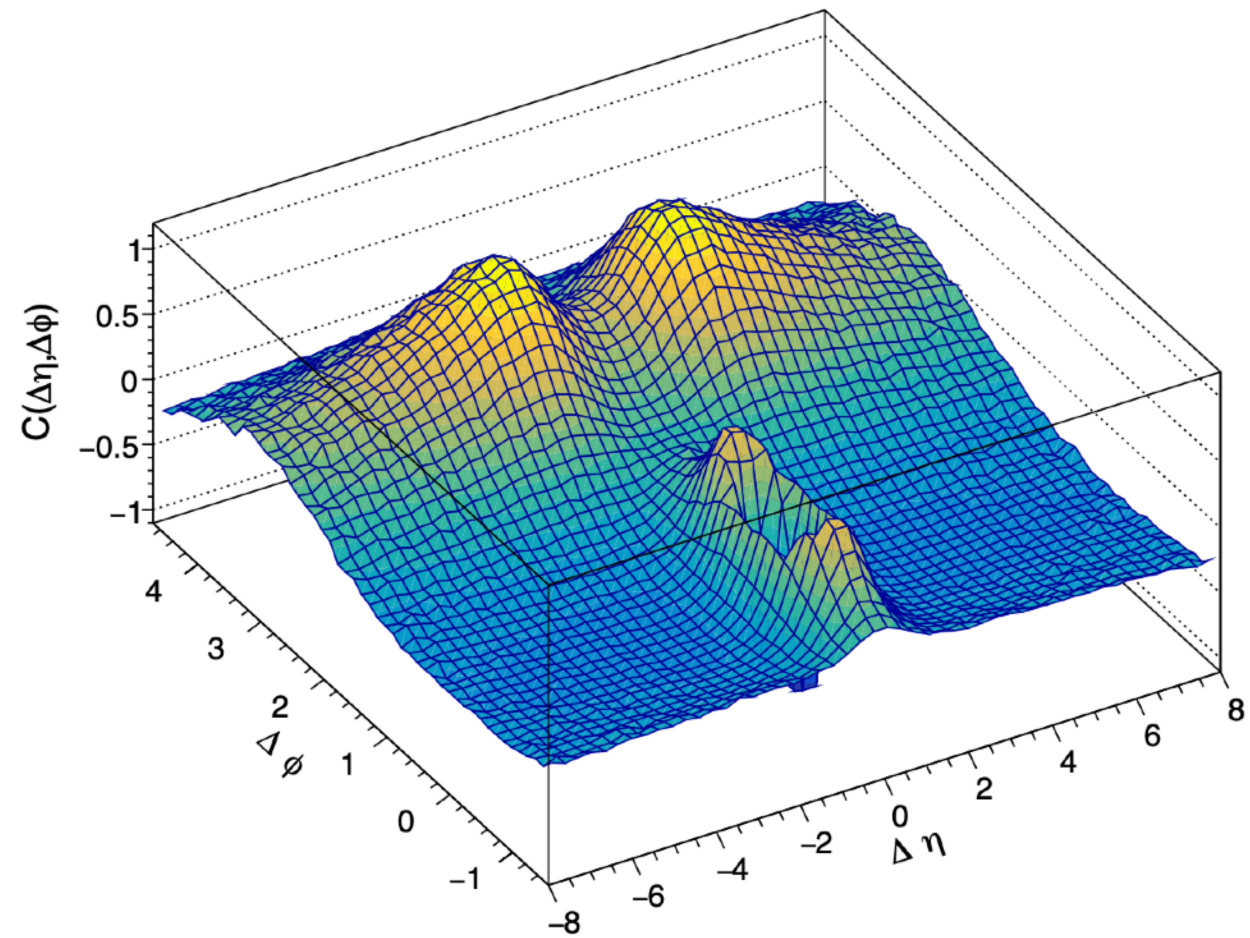
- The study of particle-particle angular correlations is an essential tool to probe the relevant dynamics that governs the strong force.
- The interpretation of the ridge in proton-proton collisions is a huge challenge but at the same time an opportunity to probe QCD in unique ways.
- Various attempts so far to give a full account of the cause behind the ridge have not succeeded.
- It could be that novel phenomena or even new physics are behind the correct interpretation of the long-range correlations, however, this possibility cannot be seriously explored before we fully understand the role of QCD. In particular, the role of perturbative QCD. First principles QCD, that is, avoiding any modelling to the extend that such an effort is feasible, needs to be confronted with the ridge effect on the basis of Monte Carlo simulations against the correlation distributions that are available from the experimental data.

Pythia simulations — pp

partonic min pT = 1 GeV
minijet min pT = 1 Gev, R = 0.5



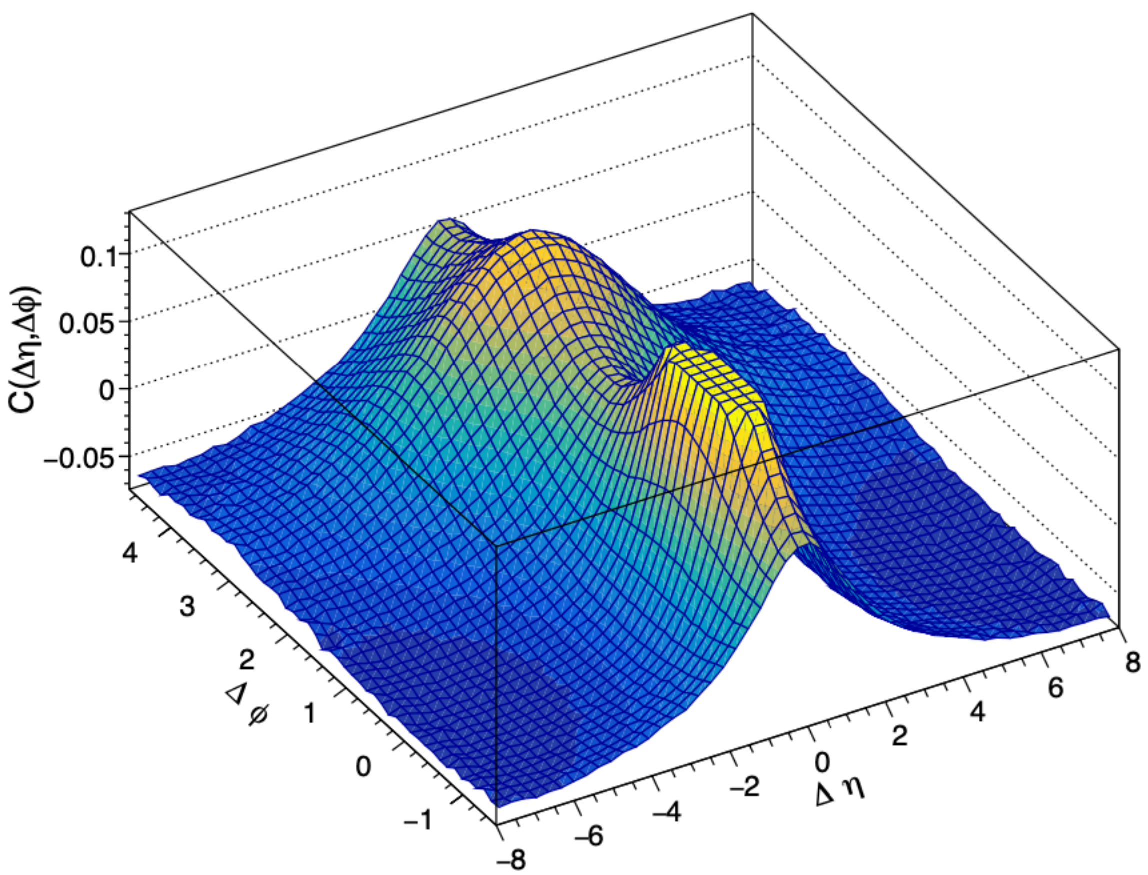
Partons



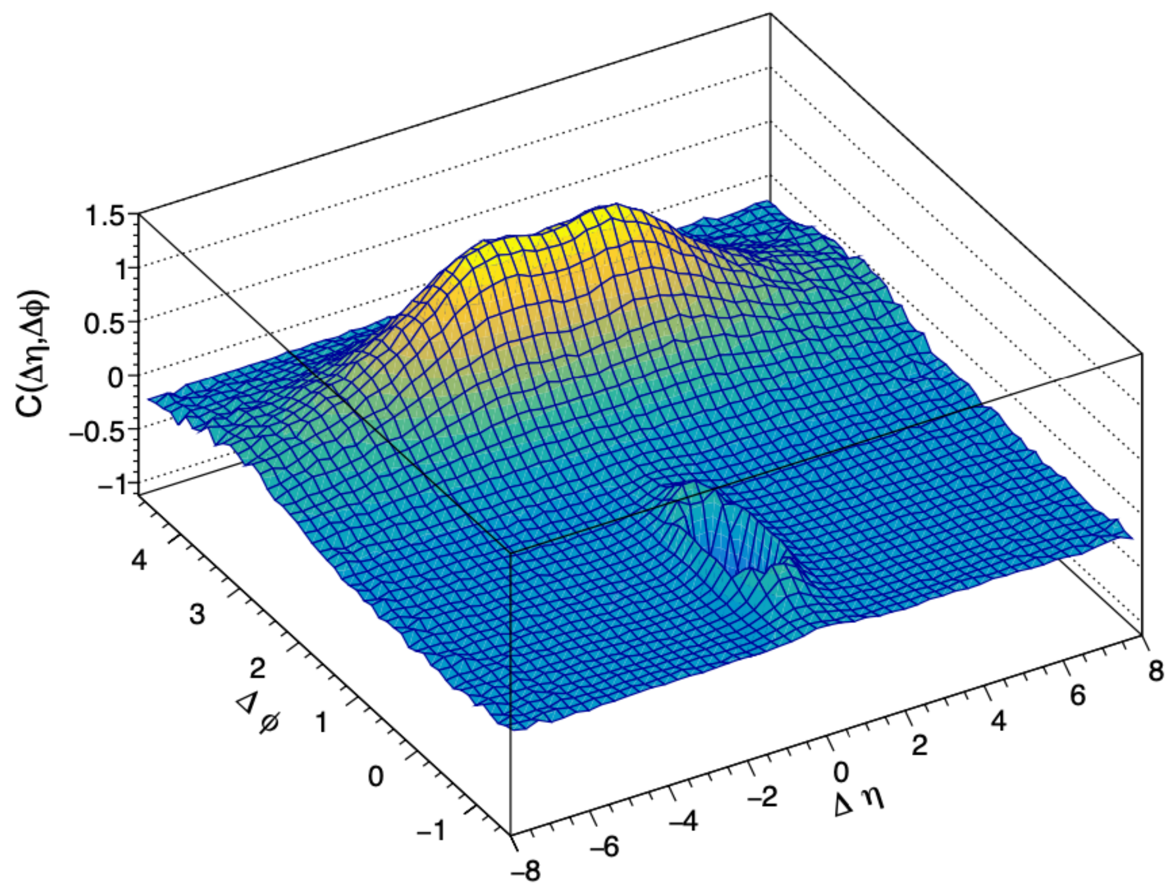
Minijets

Pythia simulations — pp

partonic min pT = 5 GeV
minijet min pT = 5 Gev, R = 0.5



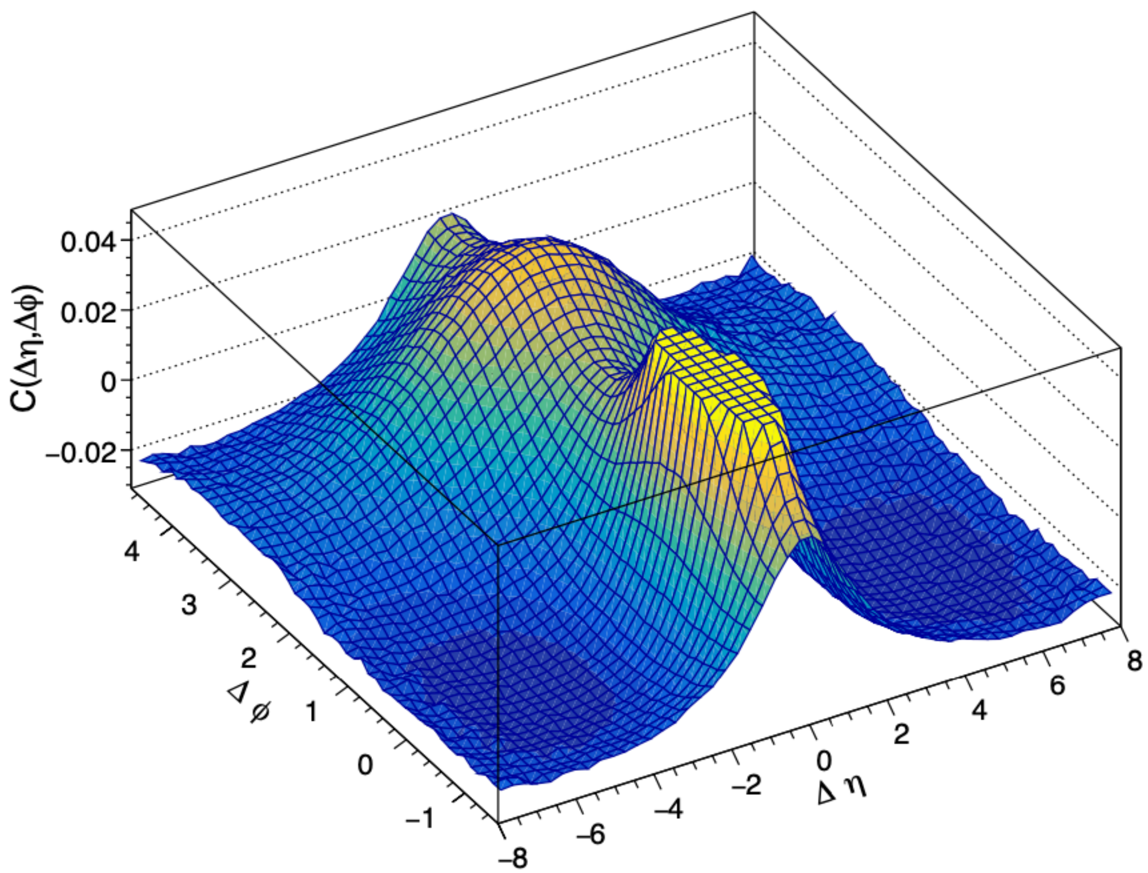
Partons



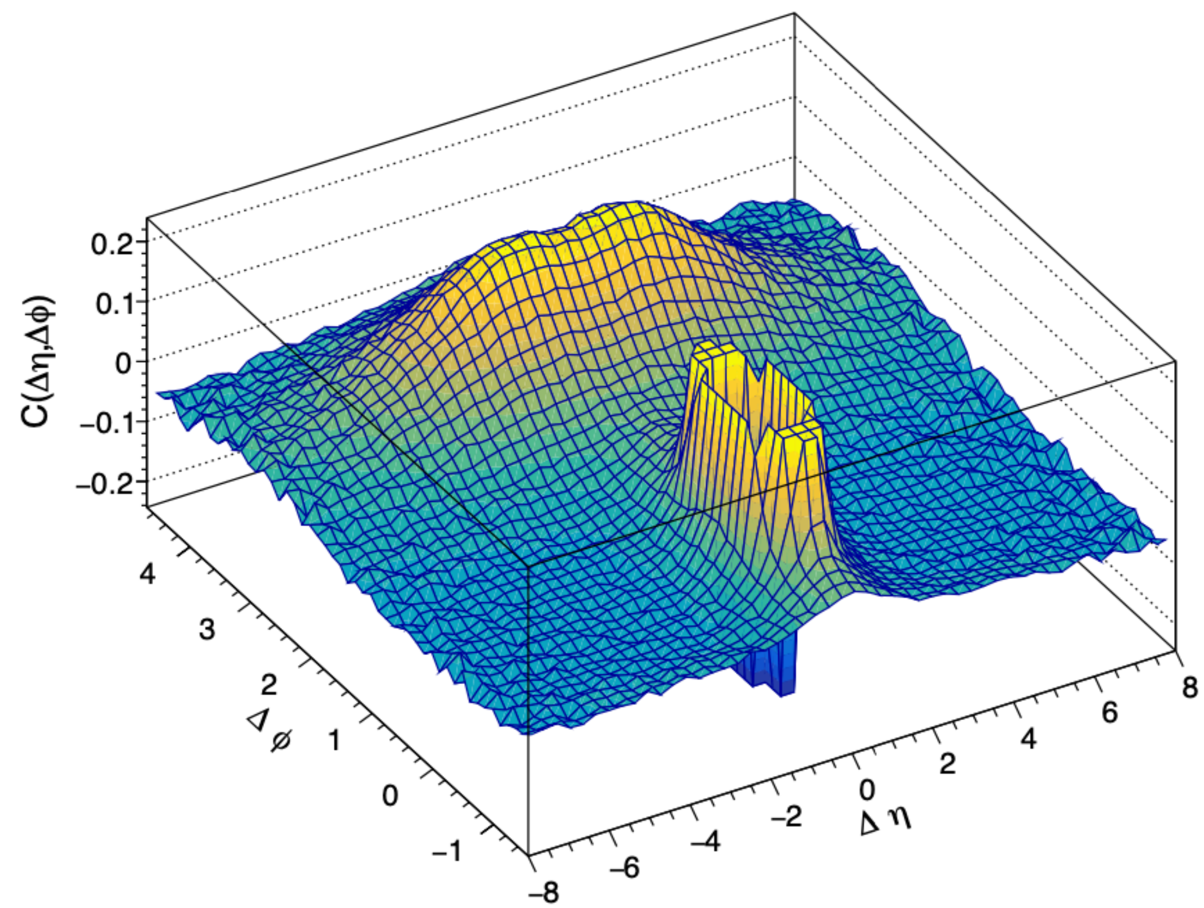
Minijets

Pythia simulations — pp

partonic min pT = 20 GeV
# of minijets > 10
minijet min pT = 5 Gev, R = 0.5



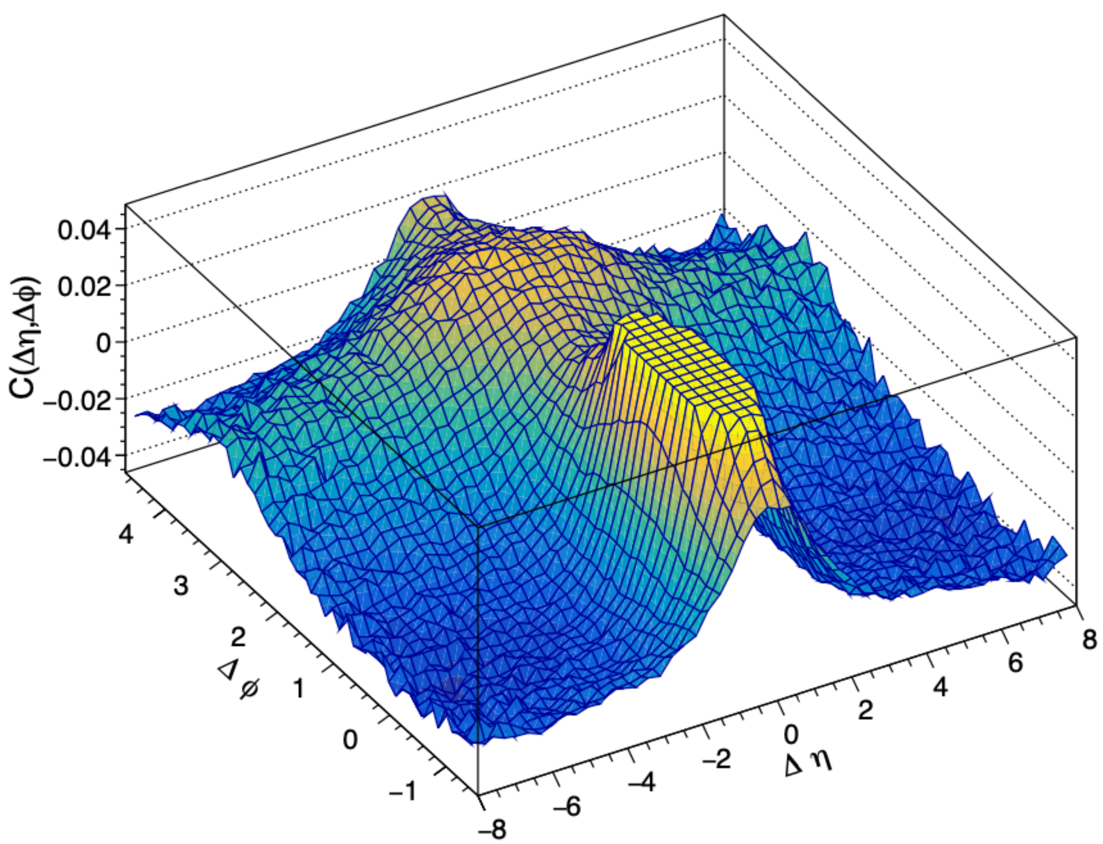
Partons



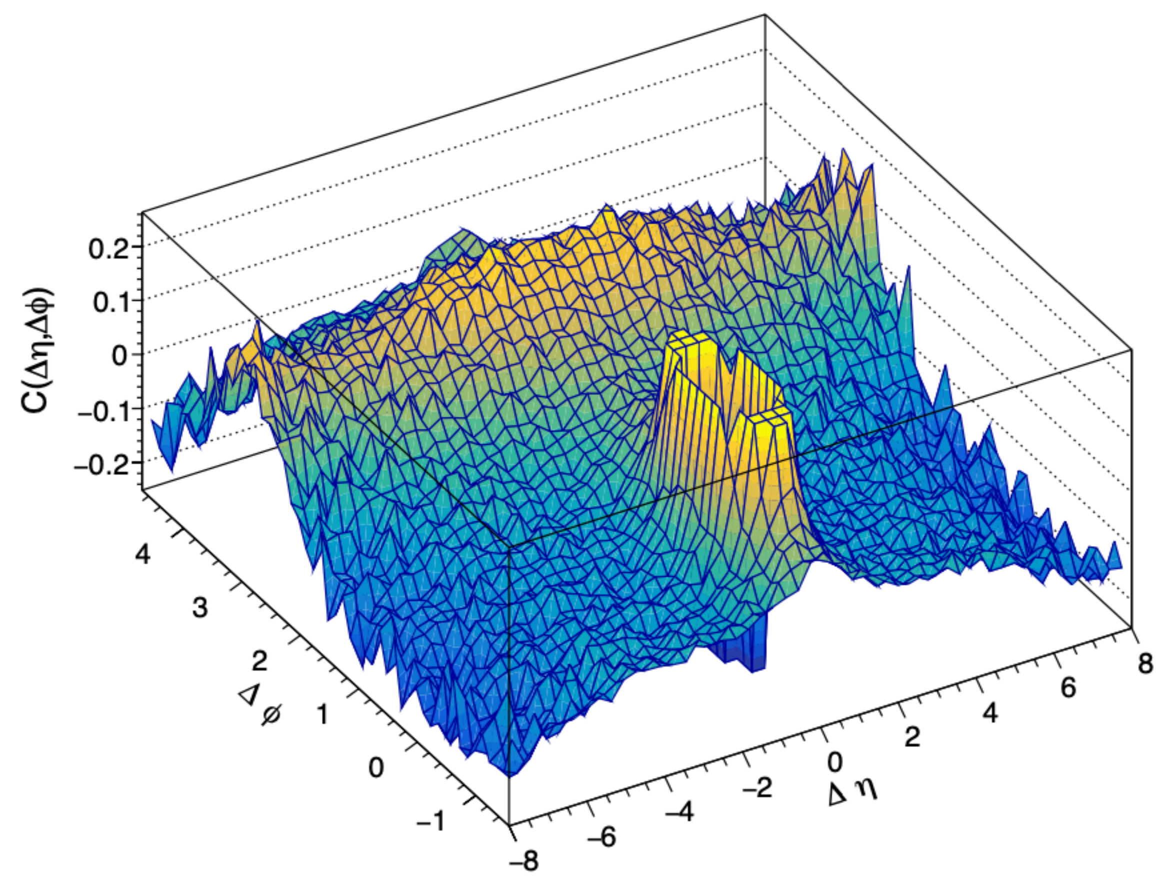
Minijets

Pythia simulations — pp

partonic min pT = 20 GeV
# of minijets > 10
minijet min pT = 5 Gev, R = 0.5
1 < ptForward/ptBackward < 1.5 (and reverse)
4 < max ΔY < 9.4



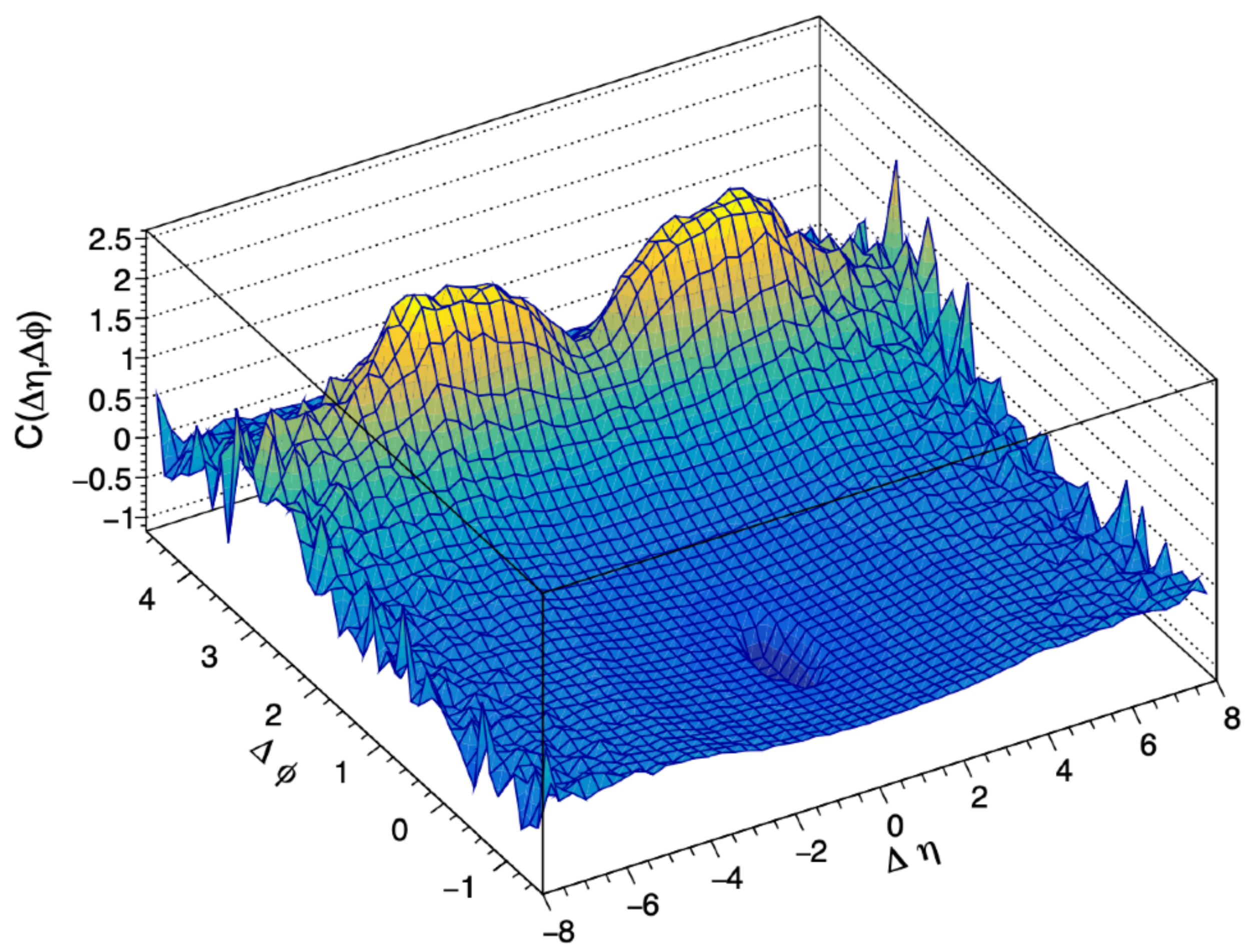
Partons



Minijets

BFKLex simulations — pp

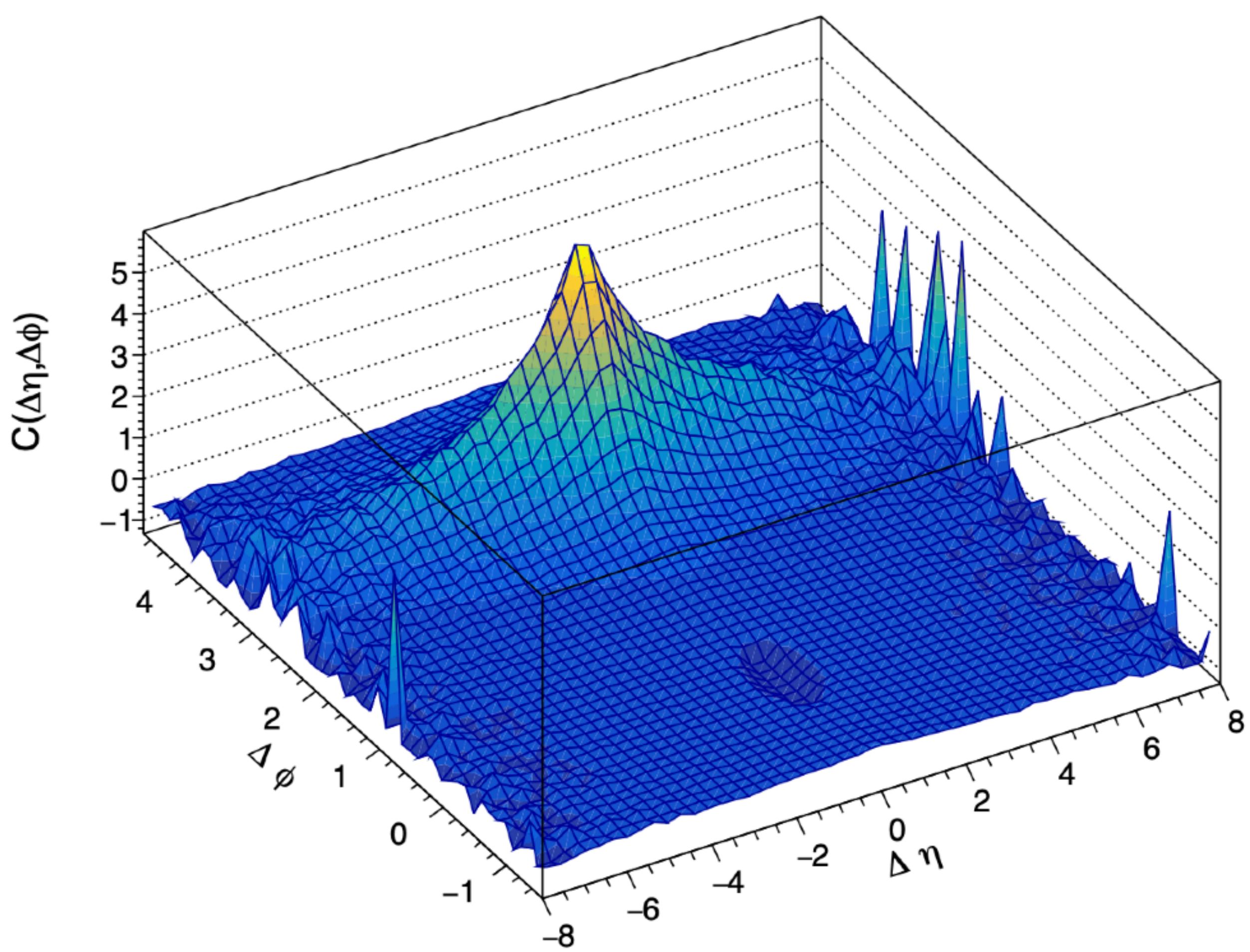
partonic min pT = 5 GeV
minijet min pT = 5 Gev, R = 0.5



Minijets

BFKLex simulations — pp

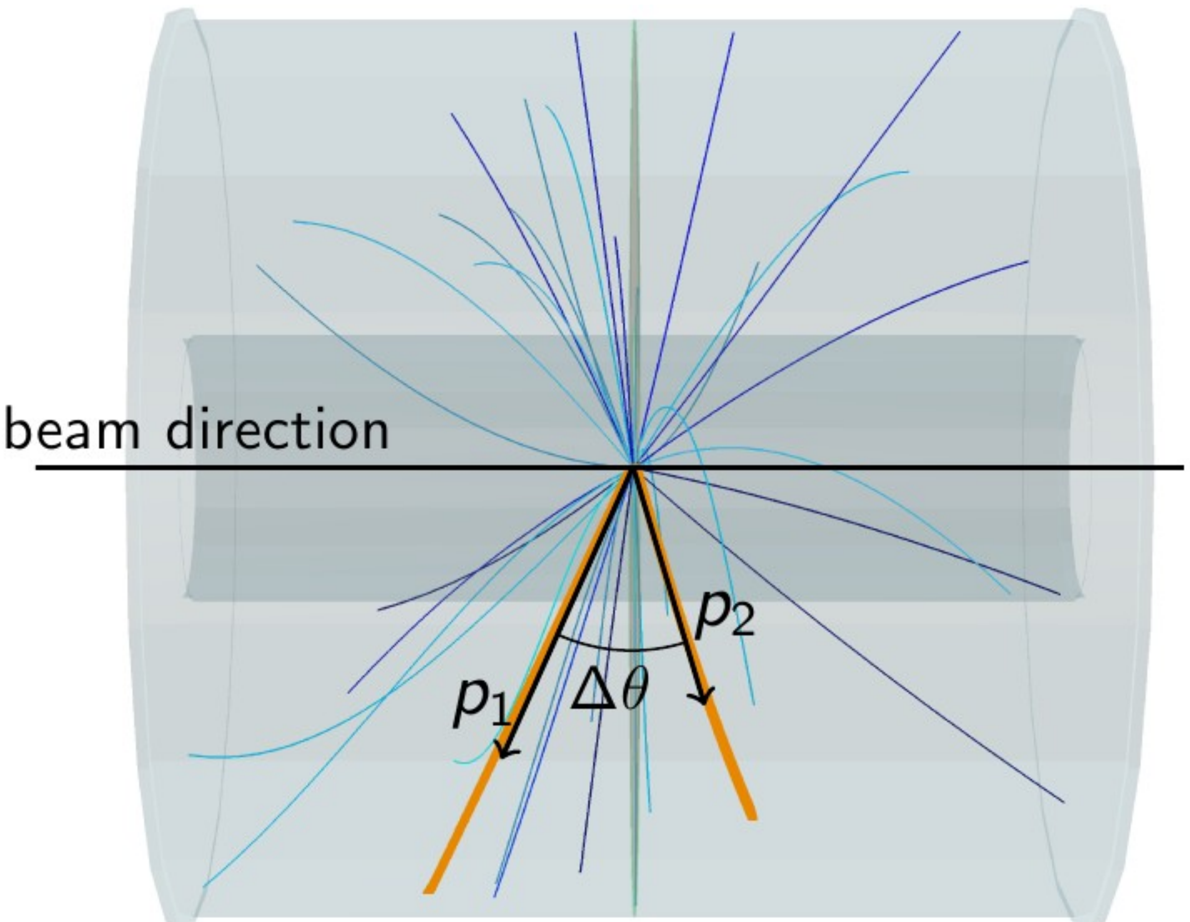
partonic min pT = 5 GeV
minijet min pT = 10 Gev, R = 0.5

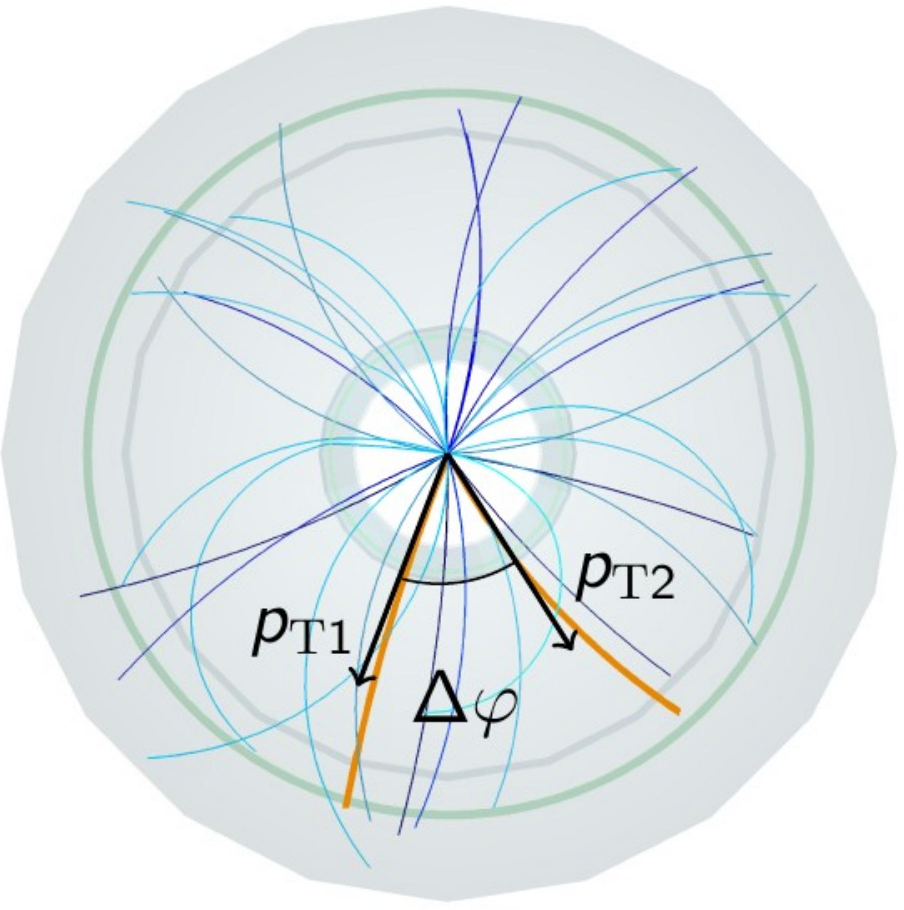


Minijets

Back up

Two-particle ΔηΔφ angular correlations





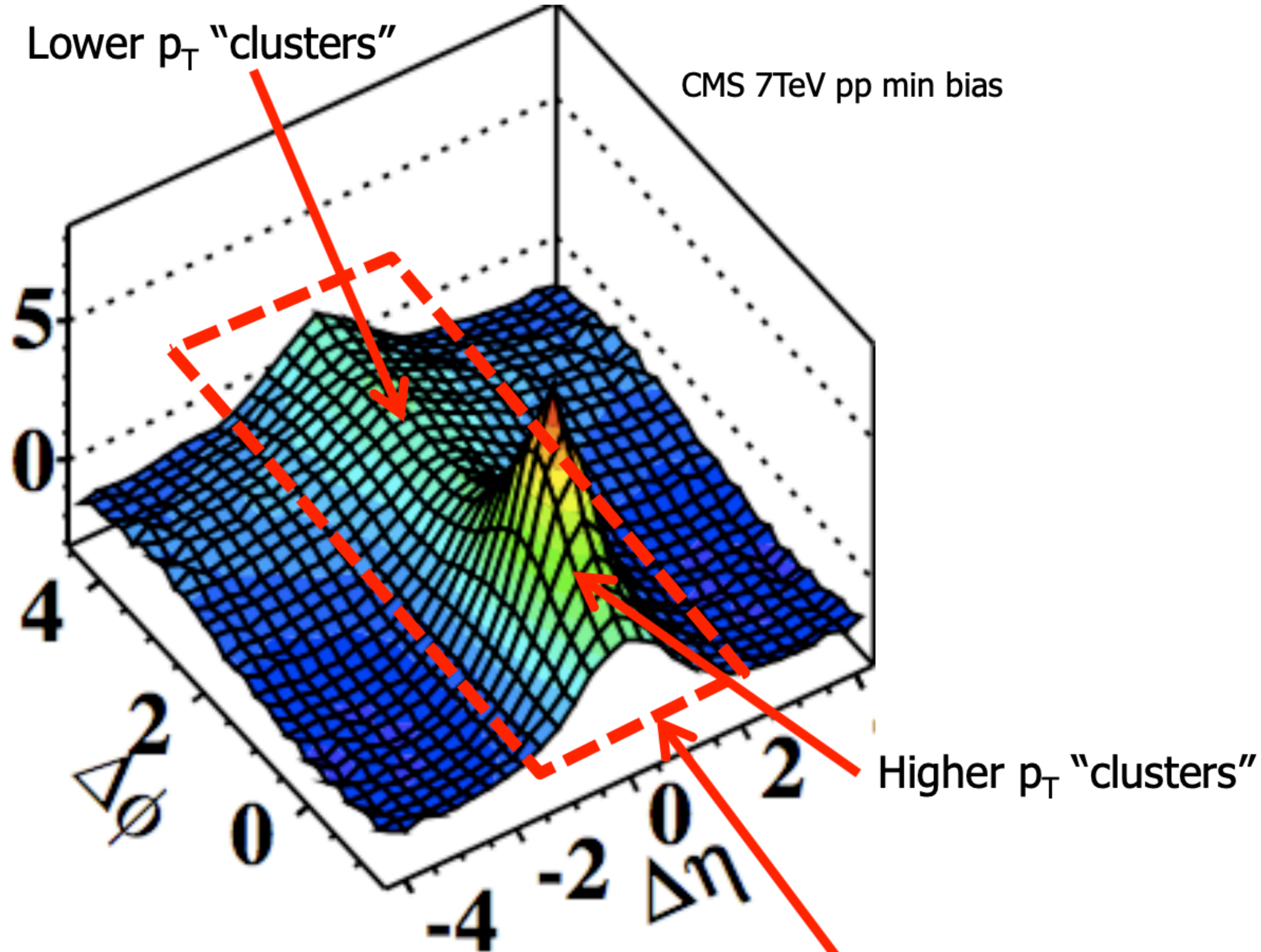
p - particle momentum;
θ - polar angle;
η - pseudorapidity:

$$\eta = -\ln\left|\mathrm{tg}\frac{\theta}{2}\right|$$

p_{T} - transverse momentum;
φ - azimuthal angle;

Fig. A. Zaborowska

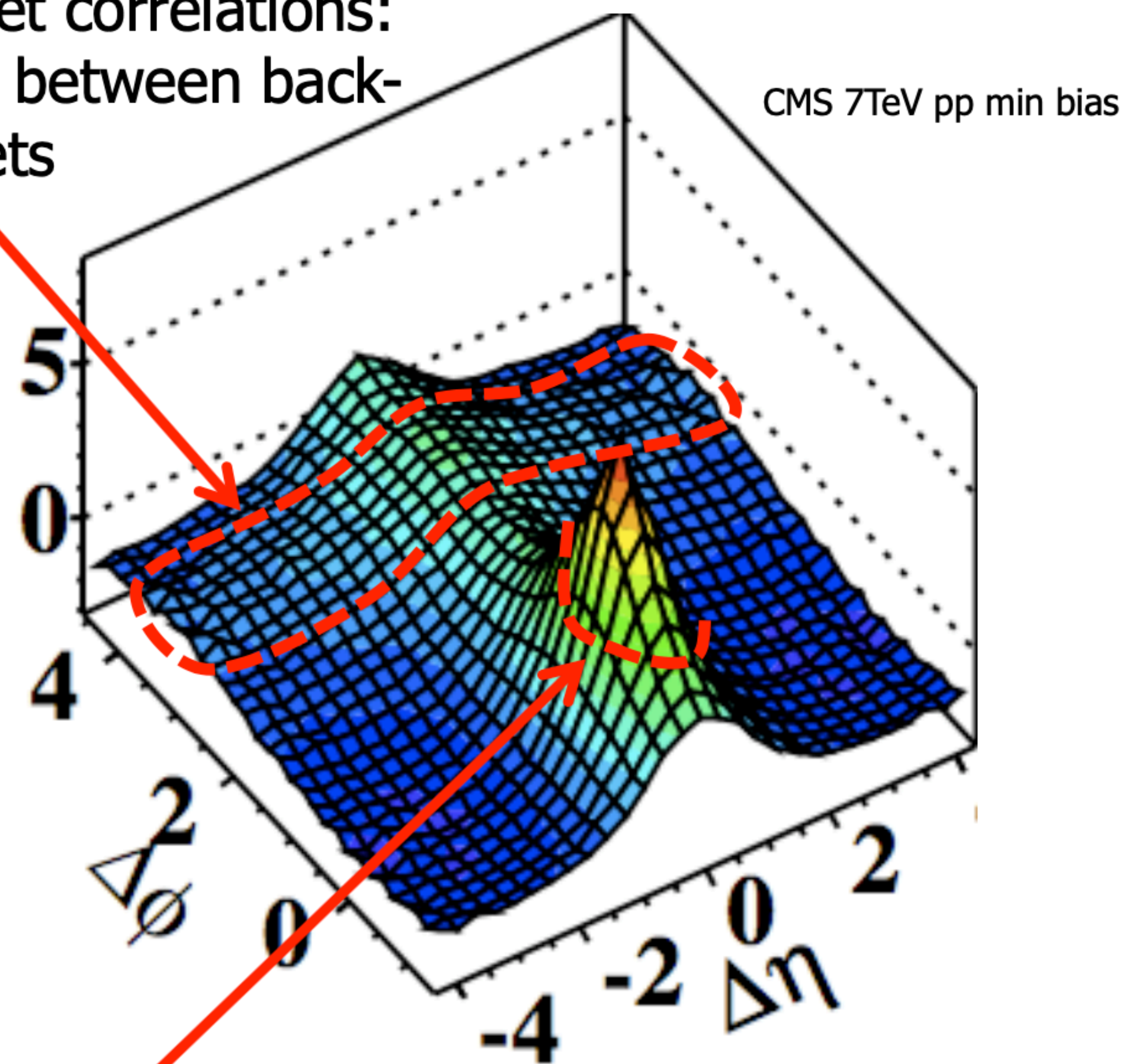
Angular Correlation Functions



Short-range correlations ($\Delta\eta$ < 2):
Resonances, string fragmentation, "clusters"

Angular Correlation Functions

"Away-side" ($\Delta\phi \sim \pi$) jet correlations: Correlation of particles between back-to-back jets



"Near-side" ($\Delta\phi \sim 0$) jet peak: Correlation of particles within a single jet